PHYSIOLOGICAL INVESTIGATION OF LOCALIZED TEMPERATURE

EFFECTS ON VIGILANCE PERFORMANCE

THESIS

Justine D. Jeroski

AFIT-ENV-14-M-30

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-14-M-30

PHYSIOLOGICAL INVESTIGATION OF LOCALIZED TEMPERATURE EFFECTS ON VIGILANCE PERFORMANCE

THESIS

Presented to the Faculty

Department of Systems Engineering

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

Justine D. Jeroski, BS

March 2014

AFIT-ENV-14-M-30

PHYSIOLOGICAL INVESTIGATION OF LOCALIZED TEMPERATURE

EFFECTS ON VIGILANCE PERFORMANCE

Justine D. Jeroski, BS

Approved:

_____//SIGNED//_____	7 March 2014
Michael E. Miller, PhD (Chairman)	Date
_____//SIGNED//_____	7 March 2014
Brent T. Langhals, Lt Col, USAF (Member)	Date
_____//SIGNED//_____	7 March 2014
Lloyd D. Tripp, PhD (Member)	Date

AFIT-ENV-14-M-30

Abstract

Despite a long history of vigilance research, the relationship between the vigilance decrement and a broad range of physiology measures has not been fully documented. In an attempt to address this gap, an experiment was designed in which participants detected critical signals displayed at random during a 40-minute simulated air traffic control vigilance task. Three localized temperature condition changes, a positive, negative, or no change, were randomly assigned to participants and administered at the halfway point of the task. In addition to collecting performance data, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) were utilized to collect a range of physiological signals from participants including cerebral oxygenation levels, heart rate, heart rate variability, blink rate, and interblink intervals. The physiology data when correlated with the decrement indicated by the performance data demonstrated a potential relationship between these measures. By identifying a vigilance decrement in individuals, one or more physiology measures may aid the design of interactive vigilance displays and compensatory measures for overcoming the vigilance decrement.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr. Michael Miller, for his guidance and support throughout the course of this thesis effort. The help and answers he provided from my many questions allowed me to understand what I was doing and stay on track to finish. I would like to thank Dr. Tripp for his knowledge and time as a wonderful resource along the way and LtCol Langhals for his insight and availability especially when it can down to crunch time. I would also like to thank Jessica Pack for her assistance in planning and conducting this study and Allison Gerren and Vince Meyer for all their help with data collection. Finally I would like to thank Chris Weyers for his support and understanding for the many long hours I spent at AFIT working on my thesis.

Justine D. Jeroski

Table of Contents

List of Figures

List of Tables

PHYSIOLOGICAL INVESTIGATION OF LOCALIZED TEMPERATURE EFFECTS ON VIGILANCE PERFORMANCE

I. Introduction

General Issue

Human systems integration has become increasingly important as interfaces are being developed to provide more information and operators are being asked to complete tasks that required more complex actions. These new challenges have been addressed through an increase in automation of the system, in some instances changing the role of the human operator from one of an active participant to that of a monitor of system status. With this change, the traditional perception-action loop is altered to one where constant awareness is required but with only occasional action.

Constant awareness or sustained attention by the human to the task or tasks being performed by the system is therefore necessary in the event of a malfunction, error, or other critical event. Vigilance, defined as the ability to maintain attention and alertness over prolonged periods of time while monitoring for rare stimuli among frequently occurring stimuli (See et al., 1995; Helton et al., 2007; Helton and Warm, 2008; Stevenson, Russell, and Helton, 2011; De Joux, Russell, and Helton, 2013), is an important capability for human system operators to have and sustain. Whereas it is relatively easy for people to be briefly attentive to a series of predictable events, maintaining attention to unpredictable events over a long period of time is difficult,

especially when the events also have a low probability of occurrence. The decline in performance over time that occurs under these circumstances is known as the vigilance decrement (See et al., 1995; Temple et al., 2000; Helton and Warm, 2008). Often, a vigilance decrement becomes noticeable after only 15 minutes of attention to a task or tasks, but depending on the nature of the task and the demand required, it could appear as rapidly as 5 minutes (Teichner, 1972; See et al., 1995). This decrement is particularly likely in situations where an operator is monitoring an automated system, such as in unmanned aerial vehicle operation, air traffic control, or during long distance driving. In these situations loss of vigilance causes events to be missed leading to an increased chance of accidents (Molloy and Parasuraman, 1996). Thus determining the factors involved with the vigilance decrement has become a crucial part of assessing human system performance in a variety of different applications.

Many factors are known to affect vigilance task performance in diverse fields of research. Most of these can be classified into three main categories, task parameters, individual subjective characteristics, and extraneous environmental or situational variables (Enander, 1989; Ballard, 1996). Environmental variables such as temperature and changes in temperature are extraneous to the task, but they may facilitate or interfere with performance through modifying levels of stress (Ballard, 1996). The effects on the human body from temperature change during vigilance tasks can therefore help facilitate vigilance or cause a decrement over time. A relevant measure of thermal stress from temperature changes affecting an individual would allow for the quantifiable data to determine the direct effects on human performance. By identifying a vigilance

decrement, physiology measures may aid the design of interactive vigilance displays and compensatory measures for overcoming attention loss.

Problem Statement

While many physiological measures of the vigilance decrement have been examined and analyzed, there has been no agreement on a preferred method that clearly identifies loss of vigilance in every individual and in a variety of situations. Thus the first goal of this research endeavor seeks to determine how physiology measures including cerebral oxygenation values, heart rate, heart rate variability, blink rate, and interblink interval, are correlated with the decline in performance as a result of an initial vigilance decrement. In addition, localized temperature changes were introduced during the second part of the vigilance task to determine their effects on performance. Physiology measures were continued to track the body's reactions to these changes and assess the effect of each condition. Adding to the current knowledge base on determining vigilance loss by further assessing the sensitivity and diagnosticity of the chosen measures, this research looked to quantifiably determine when vigilance is lost and the effects of temperature increases or decreases on human performance.

Research Objectives/Hypotheses

The primary objective of this research is to evaluate the effect of positive and negative localized temperature changes on human performance specifically with respect to vigilance tasks. This research project will accomplish this objective by concentrating on understanding the different physiological measures that can be used to measure when a vigilance decrement is present.

3

To reach the overall research goal of identifying changes in vigilance using physiology measures, there are several sub-objectives to consider, including the following:

- Analyze the performance data to quantify the vigilance decrement

- Establish a baseline understanding of the physiology measures and their correlation with performance changes

- Use the physiology measures to further examine the effects of localized temperature changes on task performance

Based on previous research on physiological measures of vigilance, as well as human performance changes as a result of temperature effect, there are some hypotheses that can be made including:

- Participants will experience an initial vigilance decrement within the first 15 to 20 minutes of the experiment.

- The physiology measures will provide a quantifiable measure that can be correlated with performance to determine when an individual is experiencing a vigilance decrement.

- Changes in temperature after which vigilance is degraded will positively affect a person's performance.

Investigative Questions

To meet the focus of this study, this thesis will strive to answer the following questions:

- What physiological measures can be used to measure a vigilance decrement?

- How do these physiological measures compare with previous research?

- How do changes in temperature affect human performance on vigilance tasks?

Methodology

The data for this research was collected during a vigilance task using human subjects in a pod with a temperature-controlled thermoelectric pad and blanket. A 40-minute simulated air traffic control task was completed, in which participants had to detect critical signals displayed at random. Three localized temperature condition changes, a positive, negative, or no change, were randomly assigned to participants and administered at the halfway point of the task. Throughout the experiment three physiology signals, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) were additionally collected.

Assumptions/Limitations

This research experiment was conducted thoroughly; however, a few assumptions and limitations must be considered. These three physiology measures were assumed to be the easiest and most widely used techniques to accurately detect and quantify loss of vigilance. This study was limited by the number of subjects that could be recruited and tested. A consistent procedure was performed for all subjects during the 90 minute experimental session; however, external factors that could affect a person's attention such as time of day, amount of sleep, or previous caffeine intake were not controlled. Additionally, this study was limited by the specifics of the vigilance task, that it was simultaneous, had a high event rate, and a signal probability of 0.033 to name a few; therefore caution must be taken when generalizing the results to all vigilance task related jobs.

5

Implications

Currently there is much research being performed on vigilance performance due to the increase in automation for human-machine systems, such as for unmanned aerial vehicle operators, air traffic controllers, or other individuals in jobs where activities such as monitoring and overseeing the system are commonplace (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2011). The goal of this research is to provide additional knowledge in the area of accurately using a physiological measure to determine vigilance over time and to assess temperature effects on improving that performance. A positive effect from an environmental change, such as increasing or decreasing the temperature individuals are exposed to, could be applied in job settings to aid the operator maintain alertness, thus providing increased performance on long duration tasks.

Preview

This chapter introduces the reasons for and the manner in which this research was approached, goals and predicted outcomes, as well as the potential impact. Following the introduction and overview of this research, two articles discuss the details of the experiment conducted, results, and conclusions reached. Chapter 2 specifically is an article that was accepted for presentation at the 2014 Industrial and Systems Engineering Research Conference. It discusses the impact of the vigilance decrement upon physiology measures during the first 20 minutes of the experiment. Cerebral oximetry and ECG data were analyzed and compared to performance scores during the vigilance decrement. Chapter 3 is a draft journal article which explains the entire experiment, relevant findings, and the conclusion for this thesis research. This article contains

analysis of the data from all 40 minutes of the experiment, including the data after the localized temperature change was applied at the halfway point. In addition to considering the performance data, analysis is completed for three physiology measures, cerebral oximetry, ECG, and EOG. Finally Chapter 5 summarizes this research endeavor, provides overall conclusions, and offers recommendations for future research.

II. Impact of Vigilance Decrement upon Physiology Measures

Abstract

Despite a long history of vigilance research, the relationship between the vigilance decrement and a broad range of physiology measures has not been fully documented. In an attempt to address this gap, an experiment was designed in which participants detected critical signals displayed at random during a 20-minute simulated air traffic control vigilance task. In addition to collecting performance data, cerebral oximetry and electrocardiography were utilized to collect a range of physiological signals from participants including heart rate, heart rate variability, and cerebral oxygenation levels in the right and left frontal areas of the brain. The physiology data when correlated with the decrement indicated by the performance data demonstrated a potential relationship between these measures. This research has implications for using physiology measures to determine the onset of human vigilance decrement to institute compensatory measures.

Introduction

Throughout history people have evolved technology, bringing about more complex and advanced systems that can perform tasks and operations faster and more accurately than before. As a result, tasks that once required physical and cognitive effort to perform can now be performed by systems through automation (Parasuraman and Riley, 1997; De Joux, Russell, and Helton, 2013). With these advancements the role of

the individual has changed from one of active involvement to one of passive supervision (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2011). As these systems are potentially fallible, human operators are left to scan information created by these new systems, to monitor their status and act only when an infrequent, but critical event, such as a system failure or emergency, arises (Warm, Parasuraman, and Matthews, 2008). Thus vigilance, or the ability to maintain attention and alertness over prolonged periods of time while monitoring for rare stimuli among frequently occurring stimuli, is required (See et al., 1995; Helton et al., 2007; Helton and Warm, 2008; Stevenson, Russell, and Helton, 2011; De Joux, Russell, and Helton, 2013).

Whereas it is relatively easy for people to be briefly attentive to a series of predictable events, maintaining attention to unpredictable events over a long period of time is difficult, especially when the events also have a low probability of occurrence. This decline in performance over time is known as the vigilance decrement (See et al., 1995; Temple et al., 2000; Helton and Warm, 2008). The vigilance decrement typically appears within the first 15 minutes of watch, but depending on the nature of the task and the demand required, it could appear as rapidly as 5 minutes (Teichner, 1972; See et al., 1995). Additionally, the vigilance decrement affects both novice and expert users (Warm, Parasuraman, and Matthews, 2008). As a result, automated human-machine systems, which have obvious benefits in the work place, have created problems related to over-reliance and waning vigilance (Molloy and Parasuraman, 1996).

The presence of the vigilance decrement has been well documented; however, the underlying cause of this performance decline is subject to debate. Currently, there are two competing theories, the mindless, boredom or under-load theory, and the resource,

mental fatigue or over-load theory. Initially the under-load theory was developed with the belief that the vigilance decrement was caused by a decline in arousal or attention to a monotonous task. This theory hypothesizes that vigilance task participants' minds would wander, leading them to think thoughts unrelated to the task causing distraction, which eventually would lead to lack of awareness of the critical signals and decreasing detection rate (De Waard, 1996; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008; Helton and Russell, 2011). More recently a new theory has proposed that vigilance tasks are difficult, stressful, and impose substantial demands on the information-processing resources of the individual. The resource theory proposes that the vigilance decrement is instead due to a decline in available attentional resources. Observers during vigilance tasks are required to make many decisions under uncertain conditions without rest. The continuous nature of this task does not allow for time to replenish resources. As a result mental resources become depleted over time, reducing the critical signal detection rates (Temple et al., 2000; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008; Helton and Russell, 2011).

As the concepts of vigilance and the vigilance decrement have developed and evolved, interest in research on this topic has gained momentum. This research is further motivated by the existence of vigilance tasks in a variety of military, industrial and medical settings, specifically the areas of air traffic control, cockpit monitoring, industrial process/quality control, airport baggage inspection, long-distance driving, robotic manufacturing, and cytological screening (Warm, Parasuraman, and Matthews, 2008; McIntire et al,. 2011). Starting in the early twentieth century, individuals such as Henry Head who first described vigilance in brain injured patients and Norman Mackworth who

studied vigilance during World War II using the famous "Clock Test" had began to quantify the source of decreased performance during vigilance tasks (Teichner, 1972; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008; Helton and Russell, 2011). The field expanded as researchers investigated human attention during vigilance tasks and human performance with a variety of different systems (Warm, Parasuraman, and Matthews, 2008). Studies of vigilance emerged with a variety of different characteristics including, multiple difficulty levels, event rates, task durations, stimuli types, and discrimination types, each with a unique experiment, but a similar goal (See et al., 1995).

Recently the field has begun to employ physiology measures to gain new perspectives into the causes of the vigilance decrement. While many physiological measures of the vigilance decrement have been examined and analyzed, there has been no agreement on a preferred method that clearly identifies loss of vigilance in every individual and in a variety of situations. Previous studies of vigilance using physiology measures have included one or more techniques to explore signals from the parts of the body such as the brain, eyes, heart, and skin (Oken, Salinsky, and Elsas, 2006; Helton et al., 2007; Helton et al., 2010; McIntire et al., 2011; De Joux, Russell, Helton, 2013; Helton, Ossowski, and Malinen, 2013). The focus of this study was to employ two of the most prevalent and readily available techniques, cerebral oximetry and electrocardiography (ECG) to further the understanding of the relationship between signals from the human body and the vigilance decrement.

Many studies have used cerebral blood oxygen saturation (rSO_2) using cerebral oximetry to quantify a vigilance decrement. There have been reasonably consistent

results reported even with a variety of possible experimental factors. Most studies have found that a decline in performance is paralleled with an increase in oxygen saturation (Funke, 2009; De Joux, Russell, and Helton, 2013); however, others have found no significant changes in oxygen saturation values with time-on-task (Helton et al., 2007; Helton et al., 2010). Greater activity in the right over the left cerebral hemisphere has been reported for easier vigilance tasks, while a bilateral activation in oxygen saturation across the two hemispheres have been reported for more difficult vigilance tasks (Helton et al., 2007; Helton et al., 2010; De Joux, Russell, and Helton, 2013; Helton, Ossowski, and Malinen, 2013).

An electrocardiogram (ECG) is a recording of the electrical activity of the heart over a period of time. The resulting signal can be analyzed to determine an individual's heart rate and heart rate variability, which have been used in numerous studies to assess mental workload. Specifically heart rate variability (HRV) has been shown to have an inverse correlation with mental workload (De Waard, 1996; Rowe, Sibert, and Irwin, 1998). Monitoring heart rate data during a vigilance task could therefore help to understand the amount of mental effort and whether the vigilance decrement is due to low mental effort (mindless theory) or instead due to a high mental effort (resource theory) (De Waard, 1996).

The purpose of this study is to detect and quantify the vigilance decrement using well known methods as to establish control data to compare for further changes in experimental procedure. Additionally, this study plans to make direct comparisons between the effects of a variety of physiology measures with changes in performance all recorded during the same vigilance task.

Method

Participants.

The participants enrolled in this study were volunteers from military and civilian employees of Wright Patterson Air Force Base. All participants had normal or corrected-to-normal visual acuity as verified using a SLOAN Multiple Group Near Vision Testing Card from Precision Vision and normal depth perception as determined using a TNO test for stereoscopic vision from Laméris Instrumenten b.v. Of the 33 participants, 21 were male and 12 were female. They ranged in age from 22 to 40 years with a mean of 28 years (SD = 5.1). And they included a representative sample of individuals, with 29 right-handed, 3 left-handed, and 1 neutral-handed participants, based upon the results of the Edinburgh Handedness Survey (Oldfield, 1971).

Apparatus and Equipment.

A Metronaps EnergyPod, shown in Figure A 1, allowed for containment of the participant during the experiment. The pod is 212.19 cm long, 145.73 cm tall, and the dome of the pod is 121.91 cm wide. The shield built into the pod functioned to prevent participants from becoming distracted by outside stimuli. The pod also permitted participants to sit in a relaxed and comfortable position throughout the experiment.

Figure A 1. The pad and blanket situated inside the pod while the shield is open and closed.

Participants wore two sensors connected to a Somanetics Invos Cerebral Oximeter 5100B as shown in Figure A 2. This system uses near-infrared spectroscopy technology to continuously and noninvasively measure blood oxygen saturation levels in the frontal areas of the left and right hemispheres of the brain. The near-infrared sensors were positioned and secured to the forehead of each participant using an adjustable headband. Care was taken to avoid the sinus cavities and any hair that might interfere with the signal. Both sensors were cleaned and tested for an effective reading between all participants.

Figure A 2. Somanetics Invos Cerebral Oximeter 5100B (left) and participant wearing adjustable headband and EOG electrodes (right).

A BIOPAC$^©$ 150 was used to perform electrocardiography (ECG). Electrodes worn on the participant's chests were attached to the BIOPAC hardware system containing an ECG amplifier for measuring the electrical signals associated with the beat of the human heart. The BIOPAC$^©$ system with electrodes are shown in Figure A 3. The BIOPAC$^©$ hardware system fed the signals into data acquisition software, AcqKnowledge®, where they were recorded and saved.

Figure A 3. BIOPAC$^©$ hardware system showing placement of ECG electrodes.

Procedure.

All participants performed the task individually in a quiet, windowless laboratory. Each participant was given an informed consent to read and sign prior to the experimental session. After completion of the consent form, the participant's visual acuity and depth perception were evaluated. Additionally their handedness was determined as right, left, or neutral using the Edinburgh Handedness Inventory. This data was recorded along with the participant's age and gender.

An in-depth description of the simulated air traffic control vigilance task was read and examples of critical and neutral signals were shown to each participant. The task involved a random presentation on a computer screen of three concentric circles with four

arrows between the two outermost circles as shown in Figure A 4. Participants viewed

approximately 30 displays/min and each display remained on the screen for 1 second.

The configuration of the four arrows between the two outer most circles changed each

time the display was updated. Displays showing arrows aligned in a potential collision

path were considered critical events and warranted an overt response from the

participants. Participants indicated a critical event by pressing a finger mouse held in

their dominant hand. Displays that showed arrows aligned in a non-collision path or safe

path were considered neutral events and required no overt response from the participants.

Examples of possible critical event displays and neutral event displays are shown in

Figure A 4. The software package was programmed to display 10 critical events

randomly within each 10 minute portion of the 20-minute vigilance task, providing signal

probability per period of 0.133 percent.
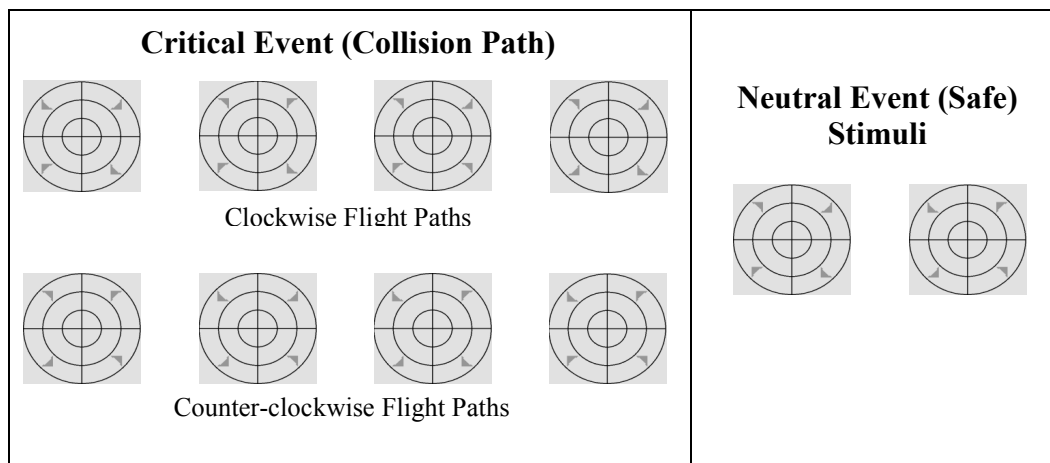
Figure A 4. Possible critical event and neutral event displays from the simulated air traffic control vigilance task.

Prior to the beginning of the practice and test sessions, the participants were asked

to sit in the pod and the cerebral oximeter and ECG sensors were fit to the appropriate

areas of their face and body. All sensors were connected to their corresponding hardware

and the resulting signals were tested to determine correct setup and sensor placement. Cerebral oximetry data was sampled at 0.2 Hz and recorded in a text file by HyperTerminal communication software. The ECG data was sampled at a frequency of 1000 Hz and recorded by the BIOPAC AcqKnowledge® software. A thermoelectric blanket was placed over the body of the participant and used to modulate the temperature of the participants in a subsequent set of trials, not discussed in this paper. A 48.26 cm (19 inch) computer monitor, used for displaying the vigilance task, was then mounted at eye-level inside the pod, approximately 60 cm from the participant.

Before the vigilance task test session, participants were given a 5-minute practice session, after which their hit and false alarm rate were calculated and feedback was given. Once the practice period was completed, participants began the 20-minute simulated air traffic control task. Custom software recorded the participant's response to every display throughout the vigilance task. Additionally, the communicator program and BIOPAC AcqKnowledge® software continued to record all physiology data. The data for this study was terminated at the 20-minute mark and the results were compiled and backed up to a secure computer. An additional period was then completed where the participants continued the vigilance task during which the temperature of the thermoelectric pad and blanket was modulated. However, the data associated with the temperature change is not reported in this paper. Finally, all the physiology sensors were removed from the participants and they were permitted to exit the pod.

Data Analysis.

This experiment was conducted to demonstrate the vigilance decrement over a 20-mintue trial of a vigilance task and to look for trends in the physiology data that mirrored

the decline in performance. As more workplaces rely on automated human-machine systems, sustained vigilance and the methods that detect vigilance has become increasingly important. Therefore the correlation of physiology data with the vigilance decrement provides potential methods for automated detection of vigilance loss.

A well-known and previously used vigilance task (Funke, 2009; McIntire et al., 2011), a simulated air-traffic control task, was chosen for the participants to complete. For each event, three types of responses were recorded during the experiment: a hit, which is a response during a critical signal; a miss, which is no response during critical signal; and a false alarm, which is a response during a neutral signal. All other events were neutral signals with no responses. From this data, the percent correct detection or hit rate and the false alarm rate were looked at for each participant individually and for the collective pool of participants.

To effectively compare the physiology measures across participants, a baseline period needed to be determined for each measure. Previous studies have used a 5-minute period prior to the task session to calculate a baseline for cerebral activity (Beam, 2002; Helton et al., 2007; Funke, 2009; Helton et al., 2010; De Joux, Russell, and Helton, 2013). However, this baseline may not be available in the operational domain, thus a more easily used baseline was determined. Cerebral oxygen saturation values recorded during the first 2 minutes of the vigilance task were averaged and used as a baseline. A percent change from the baseline was calculated for each recorded value using the following equation, %Change = ((Recorded Value – Baseline) / Baseline) * 100. An average percent change for both the left and right hemispheres was calculated for each of the remaining 2 minute periods.

Heart rate (HR) and heart rate variability (HRV) were both also analyzed as a percent change from a baseline. Heart rate was calculated from the electrocardiogram (ECG) data by identifying the location and counting the number of the R wave peaks present during normal cardiac function. The heart rate baseline for the ECG was calculated by averaging the number of R waves over the first 2 minutes of the first vigilance task period. A percent change from the baseline was calculated using the average HR for each of the remaining 2 minute periods with the following equation, %Change = ((Average for 2 Minute Period – Baseline) / Baseline) * 100. One component of heart rate variability was determined by calculating the R – R Interval (RRI), or the time between each R wave. The standard deviation of these RRIs, known as SDNN, was calculated and then divided by the average RRI value to determine the coefficient of variation of R-R (CVRR). The same baseline technique and CVRR calculation was used to determine the values for each of the remaining 2 minute periods.

Repeated measures ANOVAs were applied to determine the statistical differences in performance scores, cerebral oximetry values, and heart rate measures between the baseline period and each of the additional nine 2 minute periods. Bonferroni post-hoc tests were conducted if an overall significant difference in means was found to determine where those differences occurred. A Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. The level of significance having a probability of 0.05 was established a priori. All calculations were completed using MATLAB R2012a and SPSS Statistics 18.0.

Results

Performance.

Performance was assessed in terms of the percentage of correct detections (or hit rate) and false alarms. A repeated measures ANOVA indicated a statistically significant effect for percent correct detections over time, $F(9, 288) = 2.133$, $p = 0.027$. This data is displayed in Figure A 5.
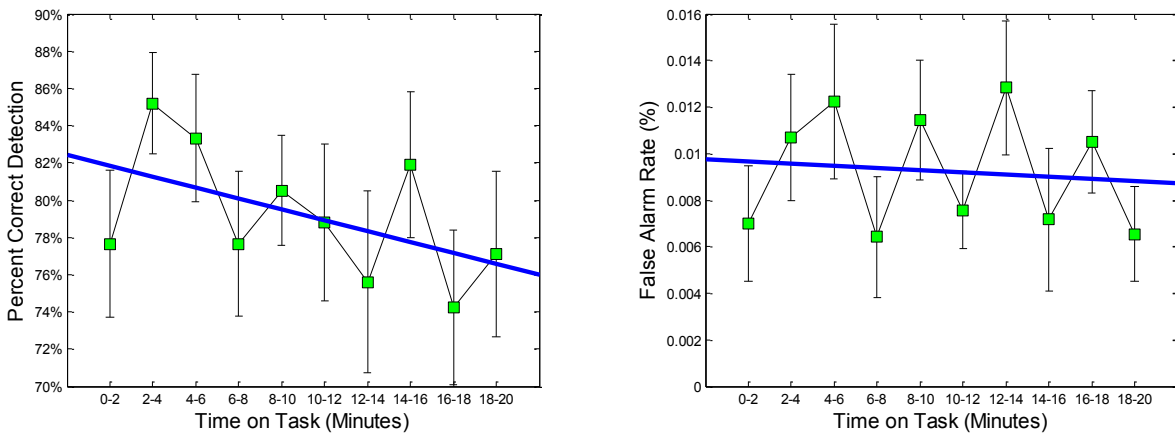
Figure A 5. Mean percent correct detection (left) and mean false alarm rate (right) over periods of watch on the vigilance task. Bold lines indicated linear trends and error bars indicate plus and minus standard error of the mean.

A repeated measure ANOVA determined that there was no significant effect of percentage of false alarms (or false alarm rate) over time. A trend line showed a relatively stable rate over time and throughout the task, the number of false alarms was very low. This data is also displayed in Figure A 5.

Cerebral Oximetry.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated a statistically significant effect of cerebral oximetry values over time, $F(3.989, 123.645) = 3.073$, $p = 0.019$ and a significant effect between percent rSO_2 change values for right

and left hemispheres, $F_{(1, 31)} = 4.539$, $p = 0.041$. A trend line was added to the data to show the overall decline over time. This data is displayed in Figure A 6.
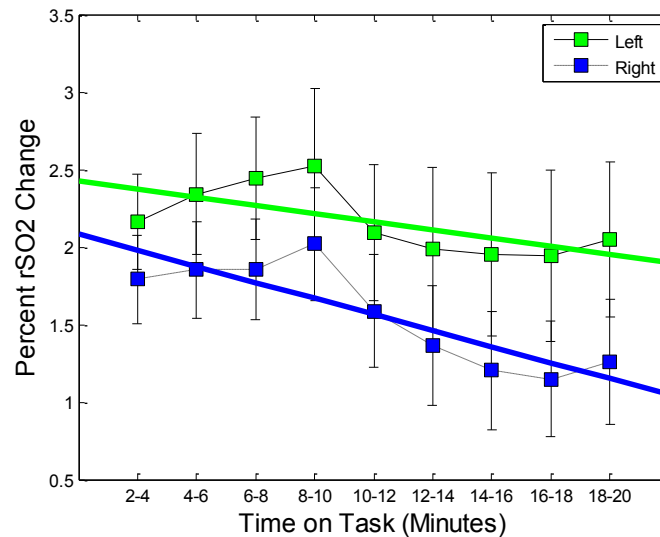
Figure A 6. Mean oxygen saturation scores for the left and right hemispheres over the period of watch. Oxygen saturation scores are based upon percent change relative to baseline. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

Heart Rate.

Heart rate measures from the ECG data included heart rate (HR) and heart rate variability (HRV). A repeated measures ANOVA determined that a significant decrease was present between time periods for percent HR change; $F_{(8, 256)} = 7.093$, $p = 0.0000$. Post hoc tests using the Bonferroni correction revealed that there was a significant decline from period 2 to periods 8 ($p = 0.007$) and 9 ($p = 0.008$) and period 3 to periods 8 ($p = 0.007$) and 9 ($p = 0.007$). The data is displayed in Figure A 7.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated there was a significant increase between time periods for percent HRV (CVRR) change; $F_{(5.724, 183.177)} = 3.407$, $p = 0.004$. Post hoc tests using the Bonferroni correction

revealed that there was a significant increases from period 2 to periods 5 (p = 0.044) and

8 (p = 0.029). The data is also displayed in Figure A 7.
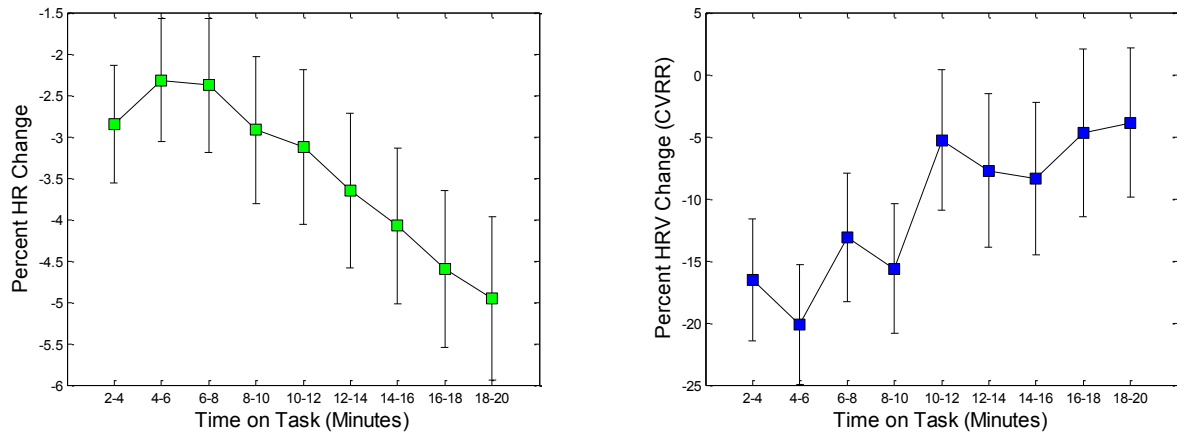
Figure A 7. Mean percent heart rate (HR) change and percent heart rate variability (HRV) over the period of watch. Heart rate measures are based upon percent change relative to baseline. Error bars indicate plus and minus one standard error of the mean.

Correlations with Vigilance.

A Pearson product-moment correlation was run to determine if there was a relationship between vigilance, or percent correct detections and any of the physiology measures. The component of HRV, coefficient of variation of R-R (CVRR) showed a significant result. All other measures were not significantly correlated with percent correct detections (hit rate). Additionally, all the physiology measures were significantly correlated with each other, as expected, considering all were measures related to blood flow. The correlation table is displayed in Table A 1.

Table A 1. Correlation Table. * indicate correlation values that are significant at the 0.05 level (2 – tailed).

	Hit Rate	Left rSO$_2$	Right rSO$_2$	Heart Rate	CVRR
Hit Rate	1				
Left rSO$_2$	.341	1			
Right rSO$_2$	.538	0.928*	1		
Heart Rate	.544	0.760*	.895*	1	
CVRR	-.740*	-.737*	-.831*	-.823*	1

Discussion

Given that the advancement and increased complexity of systems has changed the role of the individual from active involvement to passive supervision within select fields; the need to maintain attention or vigilance over prolonged periods of time has become critical for success (Parasuraman and Riley, 1997; Warm, Parasuraman, and Matthews, 2008; De Joux, Russell, and Helton, 2013). This requirement has found its way into the jobs of air traffic controllers, unmanned aerial system operators, TSA inspectors, and medical screening technicians (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2011). Therefore, determining a method to monitor the sustained attention of these individuals and intervene when a vigilance decrement occurs could improve overall task performance and reduce errors.

The fact that cerebral oxygen saturation levels increased during the first 10 minutes of the vigilance task (periods 1 to 4), suggests that increased processing demands on the brain called for increased oxygen supply to the tissue. High demand cognitive function activities cause more neurons to fire in the brain which burns glucose. A by-

product of this activity is carbon dioxide (CO_2). An increase in CO_2 leads to vasodilatation, which results in increased blood flow to the region to remove the unwanted by-products (Funke, 2009; Bélanger, Allaman, and Magistretti, 2011), and therefore an increase in available oxygen levels. As observed, from the 10 minute point, cerebral oxygen saturation levels then begin to decrease. This phenomenon could result from decreasing demand for blood flow, which occurs as available resources reach their maximum capacity. As participants' resources are depleted, their ability to perform the vigilance task diminishes. Less demand on cognitive function then results in the opposite effect, which causes a decrease of blood flow and less oxygen present (Funke, 2009). This result fits well with the resource model of vigilance and shows cerebral oxygen saturation provides an index of utilization of information-processing resources during sustained attention (Hitchcock et al., 2003).

Greater percent rSO_2 changes were seen in the left over the right hemispheres; however, there was no significant interaction between period and hemisphere, signifying bilateral activation. Difficult to discriminate targets and quick display rates (See et al., 1995), along with a lower percent correct detection rate (77 to 81 percent), would qualify this task as difficult. Therefore, it can be expected that the vigilance task initially placed increased processing demands on the brain in line with other difficult vigilance tasks. Previous research has suggested that increasing task difficulty induces a processing strategy change, from unilateral toward bilateral activation (Helton et al., 2007; Helton et al., 2010; De Joux, Russell, and Helton, 2013; Helton, Ossowski, and Malinen, 2013).

The ECG calculated measures also showed results in line with resource theory. Percent changes in heart rate (HR) and heart rate variability (HRV) both had significant

effects over periods of watch. HR results showed a negative percent change from the baseline throughout the 20 minute task and decreases further with time on task. HR was positively correlated with vigilance; however not significantly. These findings are in line with previous studies that have positive correlations between heart rate and performance scores (Eason, Beardshall, and Jaffee, 1965); however, others have reported negative correlations or no significant effects either way (Dussault et al., 2005; McIntire et al., 2011). The component of heart rate variability (CVRR) in contrast, showed a statistically significant negative correlation with vigilance performance. This agrees with previous research, that is, HRV has been shown to have inverse correlation with mental workload (De Waard, 1996; Rowe, Sibert, and Irwin, 1998). Participants were engaged initially in correctly detecting all critical signals; however, as time progressed their physiology signals changed in relation to the decline in performance.

Conclusion

The results from this 20-minute vigilance study can add further information to the field of vigilance research with the goal of being able to identify a vigilance decrement in individuals to enable counter measures to be deployed. Ideally, the deployment of such countermeasures will permit the user to achieve greater success during tasks and activities requiring sustained attention. A variety of characteristics such as duration length, type of task, event rates, and modality could have had an effect on the results of this study; however, the physiology findings were similar to previous research and pointed to the resource model theory of vigilance. Percent correct detections or hit rate decreased over time and a significant decrement was determined at the 17-18 minute

mark, in range of when a decrement is usually seen. Cerebral oximetry data showed a change from increasing to decreasing percent rSO_2 change at this point in the experiment. Heart rate measures also changed significantly near this point in the experiment. This data can add to the field of vigilance research and provide a controlled measure for this task and these physiology signals from which future research can be conducted.

Acknowledgements

References

Beam, Christina Ashley. *Effects of Sensory and Cognitive Vigilance Tasks on Cerebral Blood Flow Velocity*. Diss. University of Cincinnati, 2002.

Bélanger, Mireille, Igor Allaman, and Pierre J. Magistretti. "Brain energy metabolism: focus on astrocyte-neuron metabolic cooperation." *Cell metabolism* 14.6 (2011): 724-738.

De Joux, Neil, Paul N. Russell, and William S. Helton. "A functional near-infrared spectroscopy study of sustained attention to local and global target features." *Brain and cognition* 81.3 (2013): 370-375.

De Waard, Dick. *The measurement of drivers' mental workload*. Groningen University, Traffic Research Center, 1996.

Dussault, C., Jouanin, J. C., Philippe, M., & Guezennec, C. Y. (2005). EEG and ECG changes during simulator operation reflect mental workload and vigilance. *Aviation, space, and environmental medicine*, 76(4), 344-351.

Eason, R. G., Beardshall, A., & Jaffee, S. (1965). Performance and physiological indicants of activation in a vigilance situation. *Perceptual and motor skills*, *20*(1), 3-13.

Funke, Matthew E. *A Comparison of Cerebral Hemovelocity and Blood Oxygen Saturation Levels During Vigilance Performance*. Diss. University of Cincinnati, 2009.

Helton, William S., et al. "Cerebral lateralization of vigilance: a function of task difficulty." *Neuropsychologia* 48.6 (2010): 1683-1688.

Helton, William S., Ulrike Ossowski, and Sanna Malinen. "Post-disaster depression and vigilance: a functional near-infrared spectroscopy study." *Experimental brain research* 226.3 (2013): 357-362.

Helton, William S., and Joel S. Warm. "Signal salience and the mindlessness theory of vigilance." *Acta psychologica* 129.1 (2008): 18-25.

Helton, William S., et al. "The abbreviated vigilance task and cerebral hemodynamics." *Journal of Clinical and Experimental Neuropsychology* 29.5 (2007): 545-552.

Helton, William S., and Paul N. Russell. "Working memory load and the vigilance decrement." *Experimental brain research* 212.3 (2011): 429-437.

Hitchcock, Edward M., et al. "Automation cueing modulates cerebral blood flow and vigilance in a simulated air traffic control task." *Theoretical Issues in Ergonomics Science* 4.1-2 (2003): 89-112.

McIntire, Lindsey, et al. *Eye-Tracking: An Alternative Vigilance Detector*. INFOSCITEX CORP DAYTON OH, 2011.

Molloy, Robert, and Raja Parasuraman. "Monitoring an automated system for a single failure: Vigilance and task complexity effects." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 38.2 (1996): 311-322.

Oken, B. S., M. C. Salinsky, and S. M. Elsas. "Vigilance, alertness, or sustained attention: physiological basis and measurement." *Clinical Neurophysiology* 117.9 (2006): 1885-1901.

Oldfield, Richard C. "The assessment and analysis of handedness: the Edinburgh inventory." *Neuropsychologia* 9.1 (1971): 97-113.

Parasuraman, Raja, and Victor Riley. "Humans and automation: Use, misuse, disuse, abuse." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 39.2 (1997): 230-253.

Rowe, Dennis W., John Sibert, and Don Irwin. "Heart rate variability: Indicator of user state as an aid to human-computer interaction." Proceedings of the SIGCHI conference on Human factors in computing systems. ACM Press/Addison-Wesley Publishing Co., 1998.

See, Judi E., et al. "Meta-analysis of the sensitivity decrement in vigilance." *Psychological Bulletin* 117.2 (1995): 230.

Stevenson, Hugh, Paul N. Russell, and William S. Helton. "Search asymmetry, sustained attention, and response inhibition." *Brain and cognition* 77.2 (2011): 215-222.

Teichner, Warren H. *Predicting Human Performance III: Detection of a Simple Visual Signal as a Function of Time of Watch*. No. NMSU-ONR-TR-72-1. NEW MEXICO STATE UNIV LAS CRUCES DEPT OF PSYCHOLOGY, 1972.

Temple, Jon G., et al. "The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 42.2 (2000): 183-194.

Warm, Joel S., Raja Parasuraman, and Gerald Matthews. "Vigilance requires hard mental work and is stressful." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50.3 (2008): 433-441.

III. Physiological Investigation of Localized Temperature Effects on Vigilance Performance

Abstract

Objective: The aim of this study was to determine the effect of localized temperature changes on vigilance performance and corresponding changes in physiology measures.

Background: The presence of a vigilance decrement has been well documented; however, methods for aiding users to overcome this decrement are still in development.

Method: A 40-minute simulated air traffic control vigilance task was performed, in which participants had to detect critical signals displayed at random. Three localized temperature condition changes, a positive, negative, or no change, were randomly assigned to participants and administered at the halfway point of the task. Throughout the experiment three physiology measures, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) were collected.

Results: An initial vigilance decrement was present over time on task and localized temperature changes in the presence of this decrement improved performance. Left and right cerebral oxygen saturation values and one component of heart rate variably, the coefficient of variation of R-R, correlated with changes in vigilance and could be used as possible detection measure.

Conclusions: Physiology measures, especially cerebral oximetry and heart rate variability, may provide a meaningful method to determine the vigilance and the effects localized temperature changes have on performance.

Application: By identifying a vigilance decrement in individuals, one or more physiology measures may aid the design of interactive vigilance displays and compensatory measures for overcoming the vigilance decrement.

Keywords: vigilance decrement, performance, electrocardiography, electrooculography, cerebral oximetry

Introduction

Background.

Throughout history people have evolved technology, bringing about more complex and advanced systems that can perform tasks and operations faster and more accurately than before. As a result, tasks that once required physical and cognitive effort to perform can now be performed by systems through automation (Parasuraman and Riley, 1997; De Joux, Russell, and Helton, 2013). With these advancements the role of the individual has changed from one of active involvement to one of passive supervision (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2011). As these systems are potentially fallible, human operators are left to scan information created by these new systems, to monitor their status and act only when an infrequent, but critical event, such as a system failure or emergency, arises (Warm, Parasuraman, and Matthews, 2008). Thus vigilance, or the ability to maintain attention and alertness over prolonged periods of time while monitoring for rare stimuli among frequently occurring stimuli, is required (See et al., 1995; Helton et al., 2007; Helton and Warm, 2008; Stevenson, Russell, and Helton, 2011; De Joux, Russell, and Helton, 2013).

30

Whereas it is relatively easy for people to be briefly attentive to a series of predictable events, maintaining attention to unpredictable events over a long period of time is difficult, especially when the events also have a low probability of occurrence. The decline in performance over time that occurs under these circumstances is known as the vigilance decrement (See et al., 1995; Temple et al., 2000; Helton and Warm, 2008). The vigilance decrement typically appears within the first 15 minutes of watch, but depending on the nature of the task and the demand required, it could appear as rapidly as 5 minutes (Teichner, 1972; See et al., 1995). Additionally, the vigilance decrement affects both novice and expert users (Warm, Parasuraman, and Matthews, 2008). As a result, automated human-machine systems, which have obvious benefits in the work place, have created problems related to over-reliance on automation and waning vigilance (Molloy and Parasuraman, 1996).

The presence of the vigilance decrement has been well documented; however, the underlying cause of this performance decline is subject to debate. Currently, there are two competing theories, the mindless, boredom or under-load theory, and the resource, mental fatigue or over-load theory. Initially the under-load theory was developed with the belief that the vigilance decrement was caused by a decline in arousal or attention to a monotonous task. This theory hypothesizes that vigilance task participants' minds would wander, leading them to think thoughts unrelated to the task causing distraction, which eventually would lead to lack of awareness of the critical signals and decreasing detection rate (De Waard, 1996; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008; Helton and Russell, 2011). More recently a new theory has proposed that vigilance tasks are difficult, stressful, and impose substantial demands on the

31

information-processing resources of the individual. The resource theory proposes that the vigilance decrement is instead due to a decline in available attentional resources. Observers during vigilance tasks are required to make many decisions under uncertain conditions without rest. The continuous nature of this task does not allow for time to replenish resources. As a result mental resources become depleted over time, reducing the critical signal detection rates (Temple et al., 2000; Helton and Warm, 2008; Warm, Parasuraman, and Matthews, 2008; Helton and Russell, 2011).

Countering the Vigilance Decrement.

As the concepts of vigilance and the vigilance decrement have developed and evolved, interest in developing ways to counter the decrement and improve performance have gained momentum. A number of alerts or compensatory techniques have been studied and shown success in increasing vigilance performance. However, each of these techniques has their limitations. Possible techniques can be grouped into two types, altering the body or altering the environments. Changes to the body, such as exercise during a cognitive task have resulted in positive effects, but is not always possible or easily sustained (Etnier, 1997). Drugs, such as caffeine can be easily consumed and have also been shown to enhance performance, but can lead to unwanted side effects or addiction (Temple et al., 2000). Changes in a person's environment can include lighting, sound, or temperature changes that are then perceived by the body through one or more of the senses. Changes can be quick as to cue the observer on when a response is warranted to aid in temporary overcoming a vigilance decrement or subtle as to gradually change the environment to a new condition. These external techniques are therefore preferred due to their easy administration and fewer possible adverse side effects.

32

Localized temperature change in particular, can be controlled and directly applied to a single individual.

Previous research studying the relationship between temperature and vigilance is limited, and the results are conflicting. Mackworth found after testing subjects under ambient temperatures of 70° F, 79° F, 87.5° F, and 97° F that performance was superior at 79° F (Mackworth, 1948). Bursill also conducted a series of experiments studying the relationship between temperature and vigilance. He found that overall high ambient temperatures resulted in a greater vigilance decrement than low ambient temperatures (Bursill, 1958). Similar results were reported by others, who found quicker reaction times in colder environments (Poulton, Hitchings, and Brooke, 1965).

Physiology Measures.

Recently the field has begun to employ physiology measures to gain new perspectives into the causes of the vigilance decrement. While many physiological measures of the vigilance decrement have been examined and analyzed, there has been no agreement on a preferred method that clearly identifies loss of vigilance in every individual and in a variety of situations. Additionally the relationship between human physiology and temperature changes has been examined; however, not in the context of a vigilance study. Previous studies of vigilance using physiology measures have included one or more techniques to explore signals from the parts of the body such as the brain, eyes, heart, and skin (Oken, Salinsky, and Elsas, 2006; Helton et al., 2007; Helton et al., 2010; McIntire et al., 2011; De Joux, Russell, and Helton, 2013; Helton, Ossowski, and Malinen, 2013). The focus of this study was to employ three of the most prevalent and readily available techniques, cerebral oximetry, electrocardiography (ECG), and

electrooculography (EOG) to further the understanding of the relationship between signals from the human body and the vigilance decrement during localized temperature changes.

Many studies have used cerebral blood oxygen saturation (rSO2) using cerebral oximetry to quantify a vigilance decrement. There have been reasonably consistent results reported even with a variety of possible experimental factors. Most studies have found that a decline in performance is paralleled with an increase in oxygen saturation (Funke, 2009; De Joux, Russell, and Helton, 2013); however, others have found no significant changes in oxygen saturation values with time-on-task (Helton et al., 2007; Helton et al., 2010). Greater activity in the right over the left cerebral hemisphere has been reported for easier vigilance tasks, while oxygen saturation has indicated bilateral activation across the two hemispheres for more difficult vigilance tasks (Helton et al., 2007; Helton et al., 2010; De Joux, Russell, and Helton, 2013; Helton, Ossowski, and Malinen, 2013).

An electrocardiogram (ECG) is a recording of the electrical activity of the heart over a period of time. The resulting signal can be analyzed to determine an individual's heart rate and heart rate variability, which have been used in numerous studies to assess mental workload. Specifically heart rate variability (HRV) has been shown to have an inverse correlation with mental workload (De Waard, 1996; Rowe, Sibert, and Irwin, 1998). Monitoring heart rate data during a vigilance task could therefore help to understand the amount of mental effort and whether the vigilance decrement is due to low mental effort (mindless theory) or instead due to a high mental effort (resource theory) (De Waard, 1996).

34

Finally, an electrooculogram (EOG) is a technique that can be applied to determine eye movements such as saccadic movements, fixations, and eye blinks. Based on previous research, these eye movements have been shown to be indicative of vigilance decline over time (Langhals, Burgoon, Nunamaker, 2011; McIntire et al., 2011). This study will use this measure in conjunction with the other two measures to examine how physiology signals correspond with the vigilance decrement. Specifically, while it is reasonable to expect that the previous physiology measures will vary as a function of temperature, regardless of mental state, a strong relationship between eye movements and temperature is not expected (Glaser and Shepard, 1963; Davies and Maconochie, 2009).

The purpose of this study is to detect and quantify the vigilance decrement using well known methods during an initial experimental period. After 20 minutes, allowing for sufficient time for the onset of a vigilance decrement has passed, participants will be exposed to localized temperature changes with the intent to understand the effect of positive or negative localized temperature changes on vigilance performance. Performance will then be monitored during a second period to ascertain the sustained effects of this temperature change upon vigilance performance. Physiology measures will further be recorded to permit the correlation of physiology and performance responses.

Method

Participants.

Thirty-three participants from military and civilian employees of Wright Patterson Air Force Base volunteered for this study (21 male and 12 female). They ranged in age

from 22 to 40 years with a mean of 28 years (SD = 5.1). All participants had normal or corrected-to-normal visual acuity as verified using a SLOAN Multiple Group Near Vision Testing Card from Precision Vision and normal depth perception as determined using a TNO test for stereoscopic vision from Laméris Instrumenten b.v. The participants included a representative sample of individuals, with 29 right-handed, 3 left-handed, and 1 neutral-handed participant, based upon the results of the Edinburgh Handedness Survey (Oldfield, 1971).

Apparatus and Equipment.

A Metronaps EnergyPod, shown in Figure B 1, allowed for containment of the participant during the experiment. The pod is 212.19 cm long, 145.73 cm tall, and the dome of the pod is 121.91 cm wide. The shield built into the pod manually turned to open and close. It functioned to prevent participants from becoming distracted by outside stimuli. The pod also permitted participants to sit in a relaxed and comfortable position throughout the experiment.

Figure B 1. The pad and blanket situated inside the pod while the shield is open and closed.

Participants wore two sensors connected to a Somanetics Invos Cerebral Oximeter 5100B as shown in Figure B 2. This system uses near-infrared spectroscopy technology to continuously and noninvasively measure blood oxygen saturation levels in the frontal areas of the left and right hemispheres of the brain. The near-infrared sensors were positioned and secured to the forehead of each participant using an adjustable headband. Care was taken to avoid the sinus cavities and any hair that might interfere with the signal. Both sensors were cleaned and tested for an effective reading between all participants.
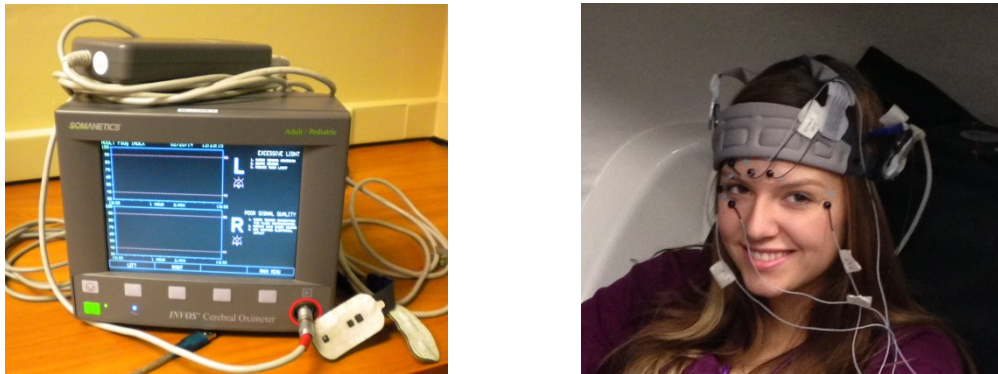
Figure B 2. Somanetics Invos Cerebral Oximeter 5100B (left) and participant wearing adjustable headband and EOG electrodes (right).

A BIOPAC[©] 150 was also used to perform electrocardiography (ECG) and electrooculagraphy (EOG). Electrodes worn on the participant's chests were attached to the BIOPAC hardware system containing an ECG amplifier for measuring the electrical signals associated with the beat of the human heart. Additionally electrodes were placed on the participant's temples and forehead to conduct EOG which measures the electrical potential provided within the muscles which predominantly move the eyes and the eye lids. The BIOPAC[©] system with electrodes are shown in Figure B 3. The BIOPAC[©]

hardware system fed the signals into data acquisition software, AcqKnowledge®, where they were recorded and saved.
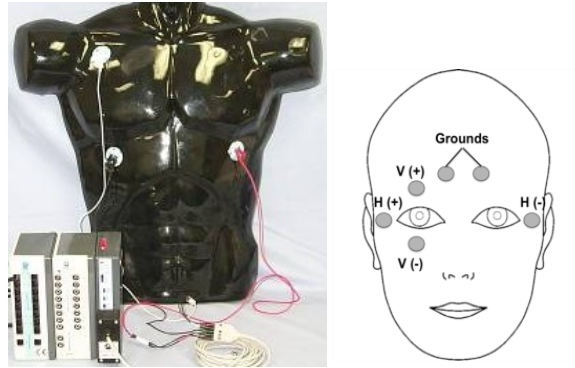
Figure B 3. BIOPAC© hardware system showing placement of ECG (left) and EOG (right) electrodes.

Procedure.

Participants were tested individually in a quiet, windowless laboratory. Each participant was given an informed consent to read and sign prior to the experimental session. After completion of the consent form, the participant's visual acuity and depth perception were evaluated. Additionally their handedness was determined as right, left, or neutral using the Edinburgh Handedness Inventory. This data was recorded along with the participant's age and gender.

An in-depth description of the simulated air traffic control vigilance task the participants were to perform was read and examples of critical and neutral signals were shown to each participant. The task involved a random presentation on a computer screen of three concentric circles with four arrows between the two outermost circles as shown in Figure B 4. Participants viewed approximately 30 displays/min and each display remained on the screen for 1 second. The configuration of the four arrows between the two outer most circles changed each time the display was updated. Displays

showing arrows aligned in a potential collision path were considered critical events and warranted an overt response from the participants. Participants indicated a critical event by pressing a finger mouse held in their dominant hand. Displays that showed arrows aligned in a non-collision path or safe path were considered neutral events and required no overt response from the participants. Examples of possible critical event displays and neutral event displays are shown in Figure B 4. The software package was programmed to display 40 critical events at random intervals within each 10 minute portion of the 40-minute vigilance task, providing signal probability per period of 0.133.
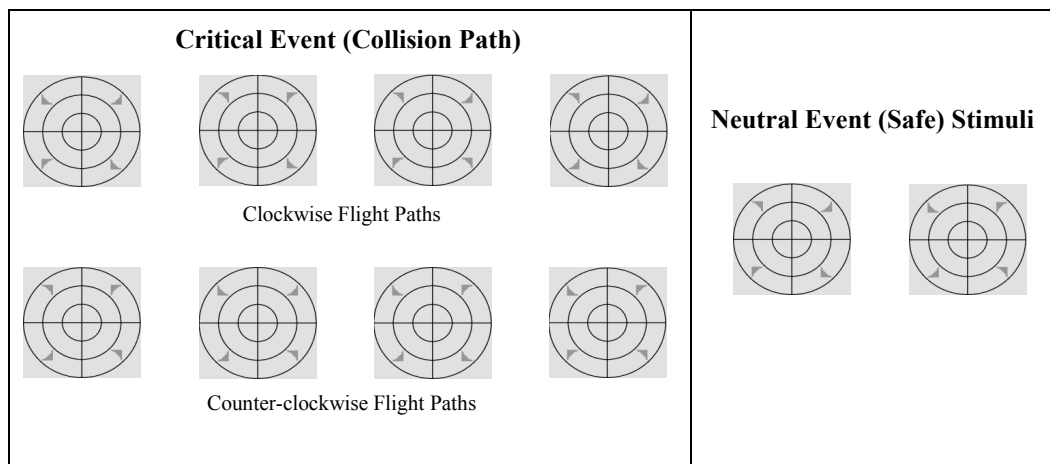
Figure B 4. Possible critical event and neutral event displays from the simulated air traffic control vigilance task.

Prior to the beginning of the practice and test sessions, the participants were asked to sit in the pod and ECG, EOG, and CO sensors were fit to the appropriate areas of their face and body. All sensors were connected to their corresponding hardware and the resulting signals were tested to determine correct setup and sensor placement. The ECG and EOG data were both sampled at a frequency of 1000 Hz and recorded by the BIOPAC AcqKnowledge® software. Cerebral oximetry data was sampled at 0.2 Hz and recorded in a text file by HyperTerminal communication software. A 48.26 cm (19 inch)

computer monitor, used for displaying the vigilance task, was then mounted inside the pod, with the center of the screen 1 m from the ground and 60 cm from the participant. This location was approximately at eye level and participants were allowed to adjust their sitting position to comfortably view the screen.

A thermoelectric pad and blanket were placed around the body of the participant and used to modulate the temperature of the participants. One of three localized temperature change conditions was randomly assigned to each participant. After 20 minutes of working on the task, the temperature of the pad and blanket increased to 110°F (hot condition), decreased to 65°F (cold condition), or remain at the ambient temperature (neutral condition).

Before the vigilance task test session, participants were given a 5-minute practice session, after which their hit and false alarm rate were calculated and feedback was given. Once the practice period was completed with satisfactory hit and false alarm rates, participants began the 40-minute simulated air traffic control task. Custom software recorded the participant's response to every display throughout the vigilance task. Additionally, the BIOPAC AcqKnowledge® software and communicator program continued to record all physiology data. The data for this study was terminated at the 40-minute mark and the results were compiled and backed up to a secure computer.   Finally, all the physiology sensors were removed from the participants and they were permitted to exit the pod.

Data Analysis.

For each event, three types of responses were recorded during the experiment: a hit, which is a response during a critical signal; a miss, which is no response during a

critical signal; and a false alarm, which is a response during a neutral signal. All other events were neutral signals with no responses. From this data, the percent correct detection or hit rate and the false alarm rate were examined for each participant individually and for the collective pool of participants.

To effectively compare the physiology measures across participants, a baseline period needed to be determined for each measure. Previous studies have used a period prior to the task session to calculate a baseline for cerebral activity (Beam 2002; Helton et al., 2007; Funke, 2009; Helton et al., 2010; De Joux, Russell, and Helton, 2013). However, this baseline may not be available in the operational domain, thus a more easily used baseline was determined. Data for each physiology measure recorded during the first 2 minutes of the vigilance task was averaged and used as a baseline. This data was then set aside and not reused for the rest of the experimental session analysis. A percent change from the baseline was calculated for each recorded value using the equation, %Change = ((Recorded Value – Baseline) / Baseline) * 100. An average percent change for all measures was calculated for each of the remaining 2 minute periods.

All electrocardiography (ECG) and electrooculography (EOG) signals were filtered using a lowpass Butterworth filter to remove noise in the signal. From the ECG data, heart rates were then calculated by identifying the location and counting the number of the R wave peaks present during normal cardiac function. One component of heart rate variability was determined by first calculating the inter-beat interval (IBI), also known as R – R Interval (RRI), or the time between each R wave. The standard deviation of these RRIs, known as SDNN, was calculated and then divided by the

41

average RRI value to determine the coefficient of variation of R-R (CVRR). These
concepts are displayed in Figure B 5.
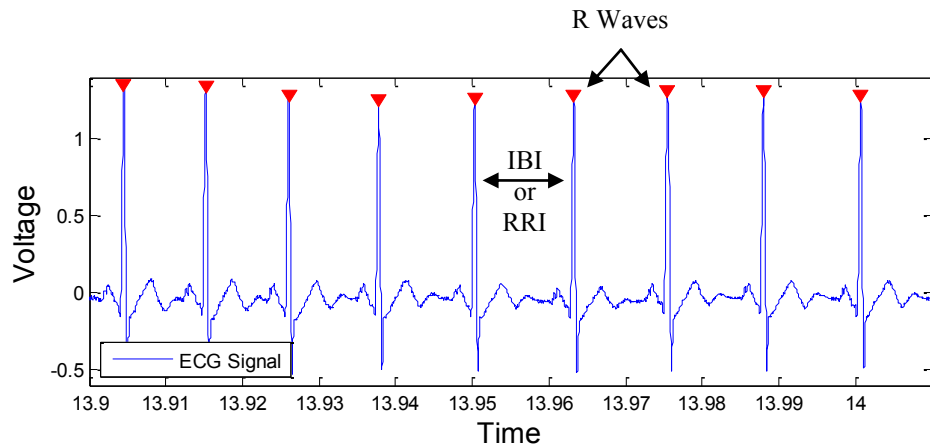
Figure B 5. ECG signal showing interbeat interval (IBI) measurement and beat peaks
identified

From the EOG data, blink rates were determined from the vertical signal. A blink
is a spike in the signal due to a rapid opening and closing of the eyelid, lasting in length
between 100 – 400 milliseconds. To determine when a blink occurred, a moving average
of the vertical signal with an average greater than 400 points was completed, and the
average was shifted up by a magnitude determined by visual inspection. All peaks above
this line were determined as blinks, while peaks below were ignored. The result of this
analysis for a typical signal is displayed in Figure B 6.
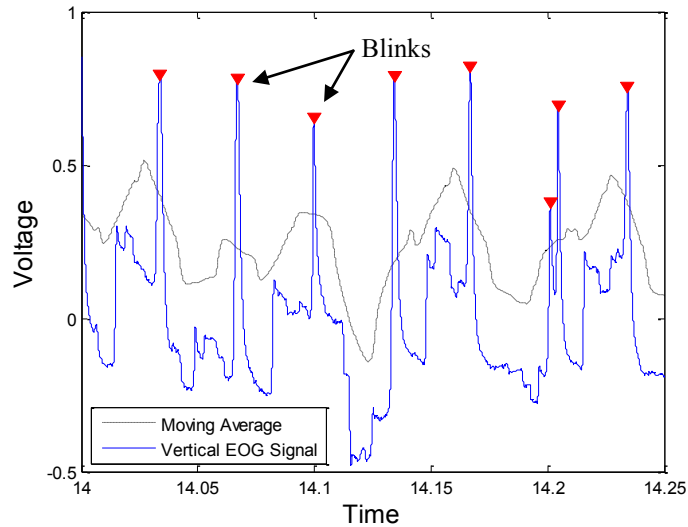
Figure B 6. Vertical EOG signal graphed with a shifted moving average line and blink peaks identified.

Missing data from the BIOPAC system due to equipment error or a lose sensor for 3 of the 33 subjects further complicated the analysis. To address the lack of values, an average using the remaining values for that particular temperature condition was calculated and used to complete the data sets. This method allowed for further analysis without significantly skewing the results.

Repeated measures ANOVAs were applied to determine the statistical differences in performance scores, cerebral oximetry values, and heart rate measures between the baseline period and each of the additional nine 2 minute periods. Bonferroni post-hoc tests were conducted if an overall significant difference in means was found to determine where those differences occurred. A Greenhouse-Geisser correction was applied when the assumption of sphericity was violated. The level of significance having a probability of 0.05 was established a priori. All calculations were completed using MATLAB R2012a and SPSS Statistics 18.0.

43

Results

Performance.

Performance was assessed in terms of percent correct detections (or hit rate) and false alarms. The percentage of correct detections is displayed in Figure B 7. The figure shows that the detection percentage declined over time during the first half of the experiment when all participants were experiencing a neutral temperature. At the temperature change, performance increased for those participants in the two temperature change conditions as shown in Figure B 7 by the increasing slope of the average point line. After the temperature change, detection percentage improved for participants in the cold condition but decreased for those who experience the hot condition. Interestingly, the participants in the neutral condition experienced the largest increase, or steepest positive trend line slope. A repeated measures ANOVA indicated no statistically significant effect for percent correct detections over time.
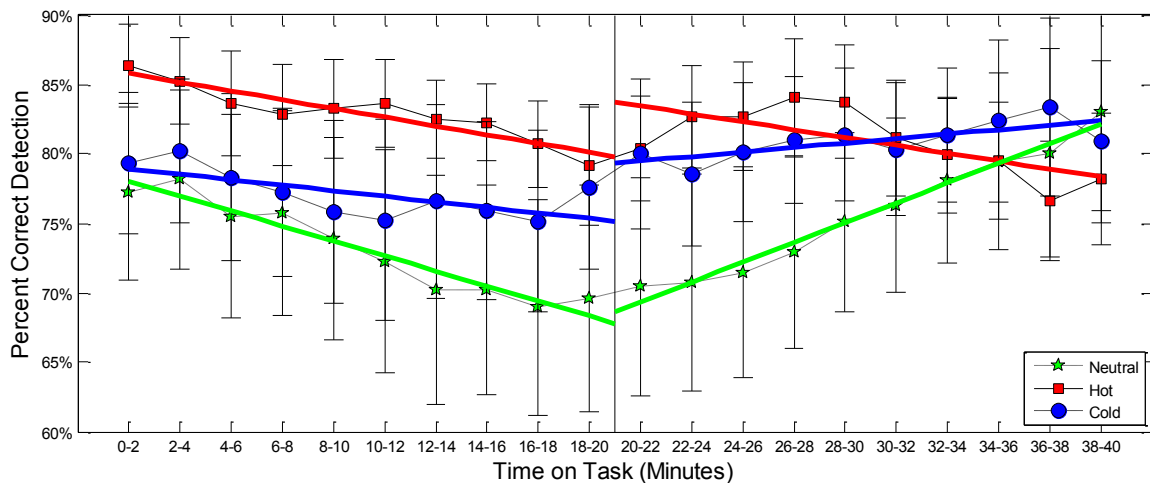
Figure B 7. Mean percent correct detection over time on task. The vertical line indicates when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus standard error of the mean.

False alarm rates are displayed in Figure B 8. A repeated measure ANOVA determined that there was a significant effect of percentage of false alarms (or false alarm rate) over time, $F(2.969, 29.694) = 7.122$, $p = 0.001$. An examination of the false alarm rates revealed that errors of commission were very low, less than 1.4 % for all participants. Therefore no further examination of the false alarm data was completed. Trend lines for the average values over time on task show a decrease for all conditions.
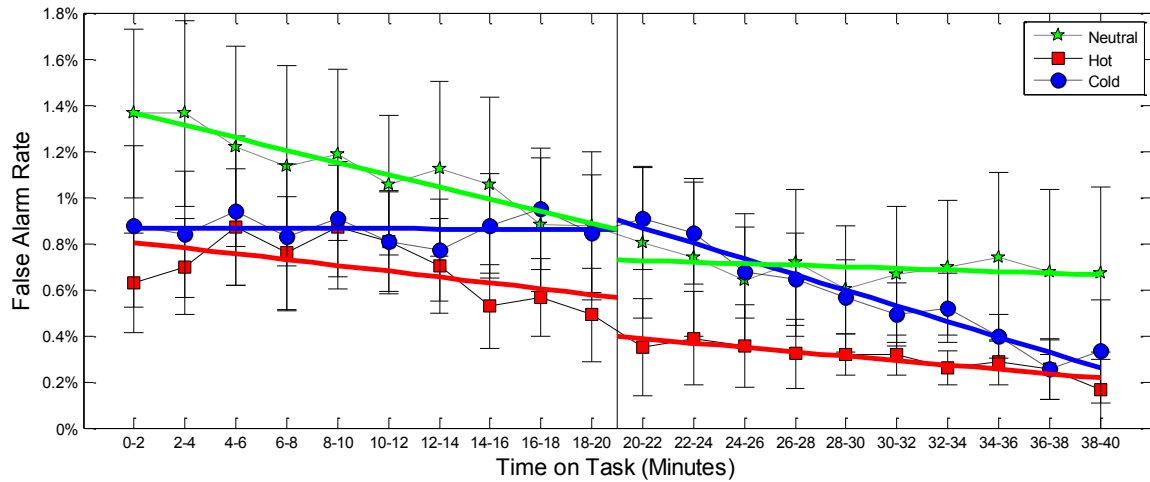
Figure B 8. Mean false alarm rate over time on task. The vertical line indicates when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus standard error of the mean.

Cerebral Oximetry.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated a statistically significant effect of cerebral oximetry values over time, $F(3.807, 34.263) = 3.851$, $p = 0.012$ and a significant effect for the interaction between temperature and time, $F(3.237, 29.132) = 4.576$, $p = 0.008$. The interaction between temperature, time, and hemisphere also had a significant effect, $F(2.604, 23.437) = 4.522$, $p = 0.015$. The data for all subjects for the neutral, hot, and cold condition is displayed in Figure B 9 (a-c), respectively.

The figures show consistent decreasing rSO$_2$ values for the first 20 minutes of the experiment across all conditions as participants experience a vigilance decrement. At the temperature change, rSO$_2$ values of participants experiencing the hot condition slightly increased whereas those in the cold condition decreased considerably. After the temperature change, rSO$_2$ values of participants in the neutral condition continued to decrease, while the rSO$_2$ values of those participants in the hot and cold conditions began to increase. Finally, rSO$_2$ values for participants in the neutral condition showed a greater separation between the right and left values than either of the other conditions.
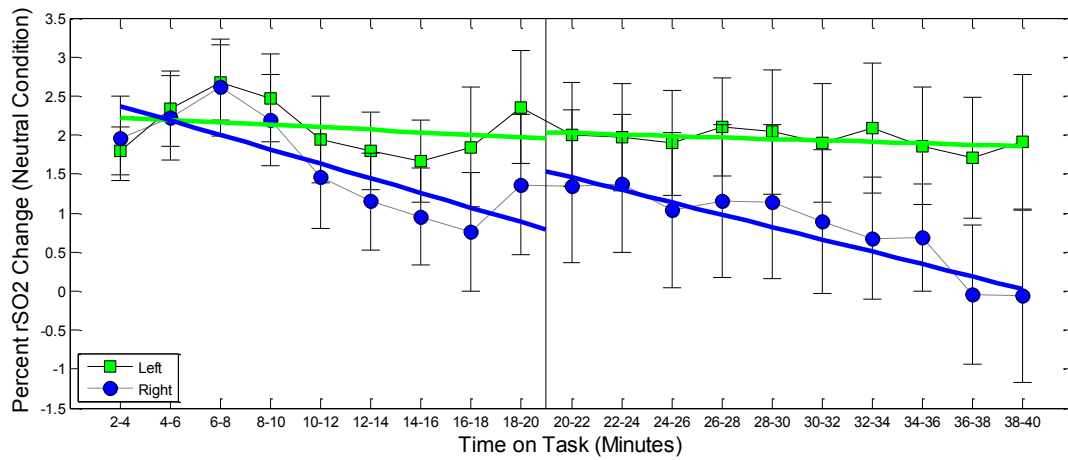
(a)
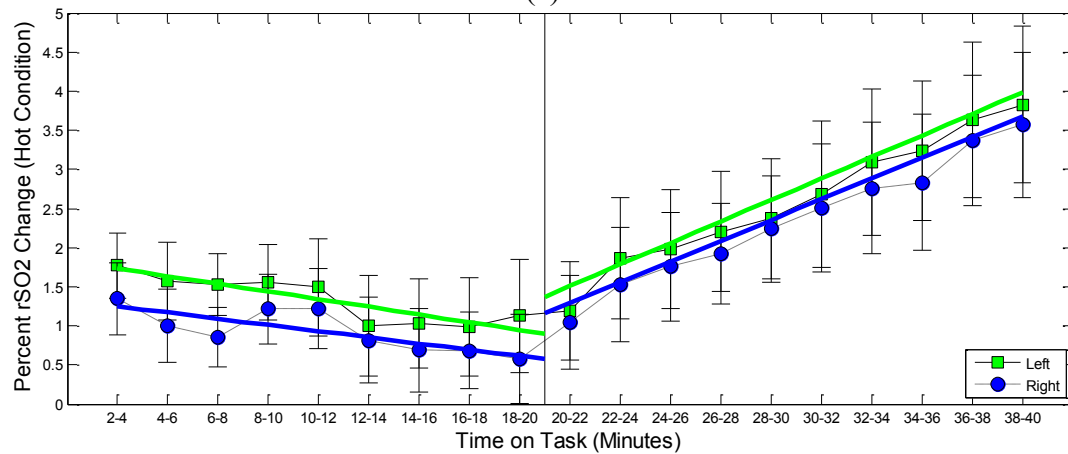
(b)
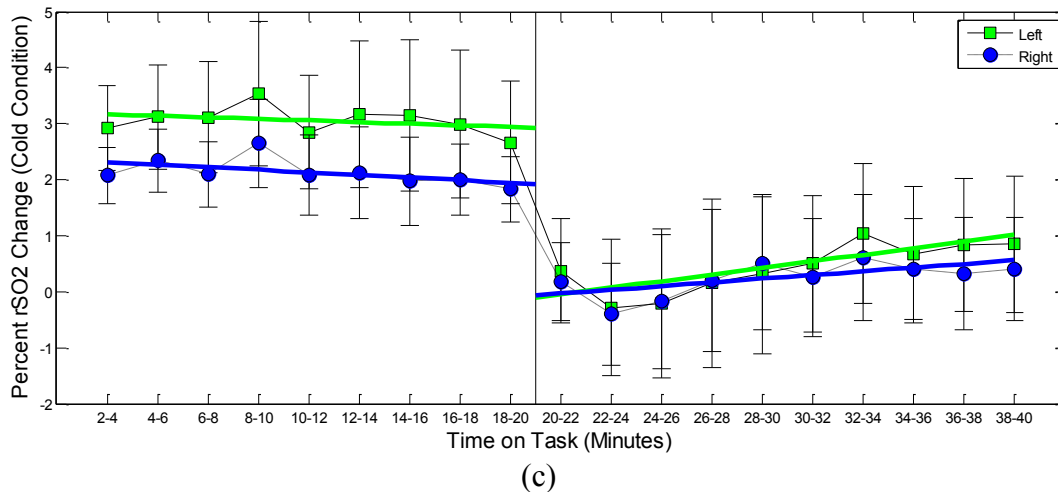
(c)

Figure B 9. Mean oxygen saturation scores for the neutral condition (a), hot condition (b), and cold condition (c) for both the left and right hemispheres over time on task. Oxygen saturation scores are based upon percent change relative to baseline. The vertical lines indicated when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

Electrocardiography.

Heart rate measures from the electrocardiography (ECG) data included heart rate (HR) and heart rate variability (HRV). A repeated measures ANOVA determined that no significant effect was present between time periods for percent HR change. The data is displayed in Figure B 10. The trend lines in the figure show that HR decreases consistently during the first 20 minutes of the experiment. After the halfway point, the neutral condition continues to decrease but to a lesser extent and HR for both temperature conditions increases.
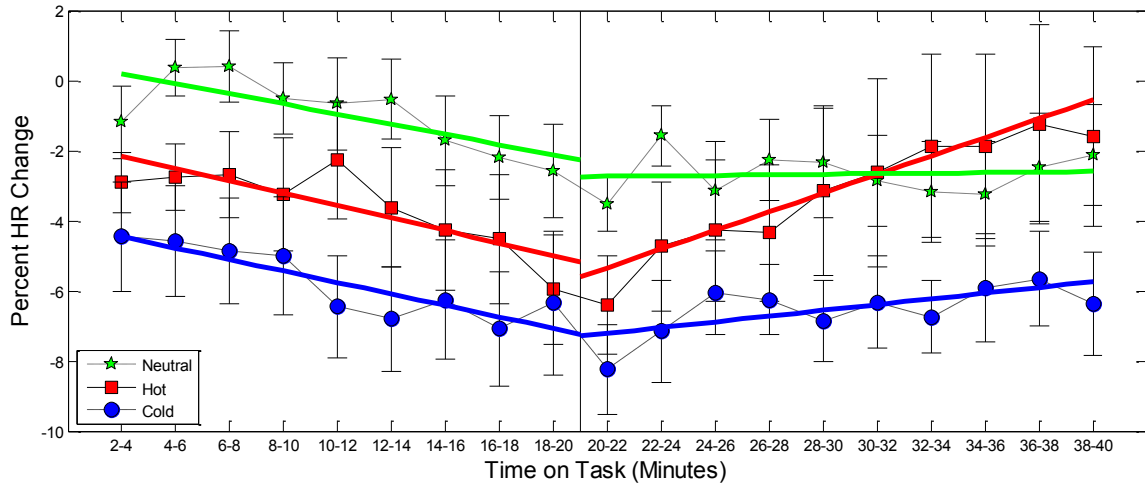
Figure B 10. Mean percent heart rate (HR) change over time on task. Heart rate measures are based upon percent change relative to baseline. The vertical lines indicated when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated there was a significant effect between time periods for percent CVRR change; $F_{(6.079, 60.787)} = 6.371$, $p = 0.000$. Post hoc tests using the Bonferroni correction revealed that over time there was significant increases from period 2 and periods 13 ($p = 0.020$), 17 ($p = 0.030$), and 18 ($p = 0.003$). The data is displayed in Figure B 11. The trend lines in the figure show CVRR increasing during the first 20 minutes of the experiment. After the temperature change, the neutral and hot conditions continue to increase, while the cold condition sees a slight decrease in CVRR.
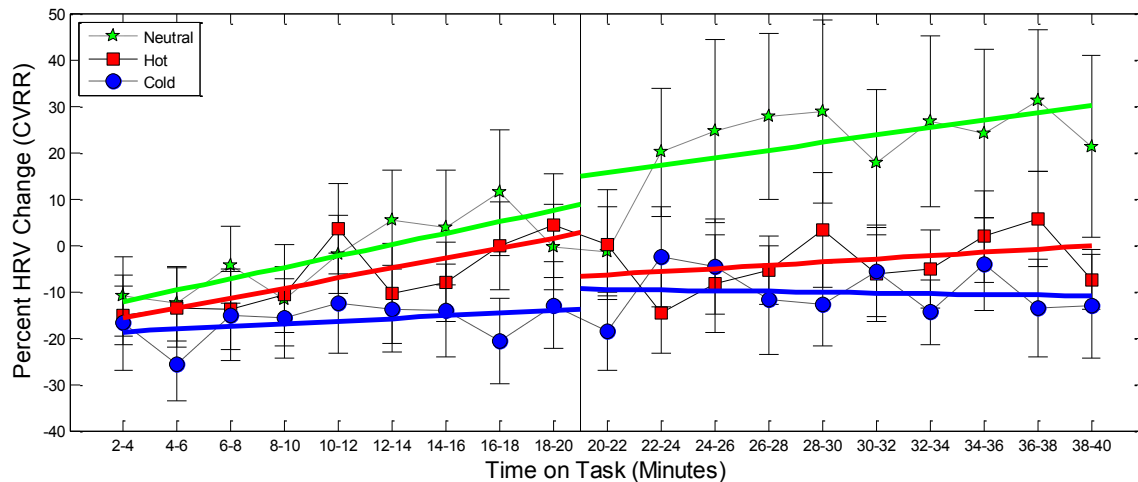
Figure B 11. Mean percent heart rate variability (HRV) change over time on task. Heart rate measures are based upon percent change relative to baseline. The vertical lines indicated when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

Electrooculography.

Eye measures from the electrooculography (EOG) data included blink rate and interblink interval. A repeated measures ANOVA with a Greenhouse-Geisser correction determined that a significant effect was present between time periods for percent blink rate change; $F(3.023, 30.225) = 3.928$, $p = 0.017$. Post hoc tests using the Bonferroni correction revealed that there was a significant difference from period 1, 2 – 4 minutes to period 17, 34 – 36 minutes ($p = 0.026$). The data is displayed in Figure B 12. Trend lines in the figure show that blink rate increased initially across all conditions. After the first 20 minute period, the neutral and cold conditions continue to increase, however at a less rate. Blink rate for the hot condition instead began to decrease.
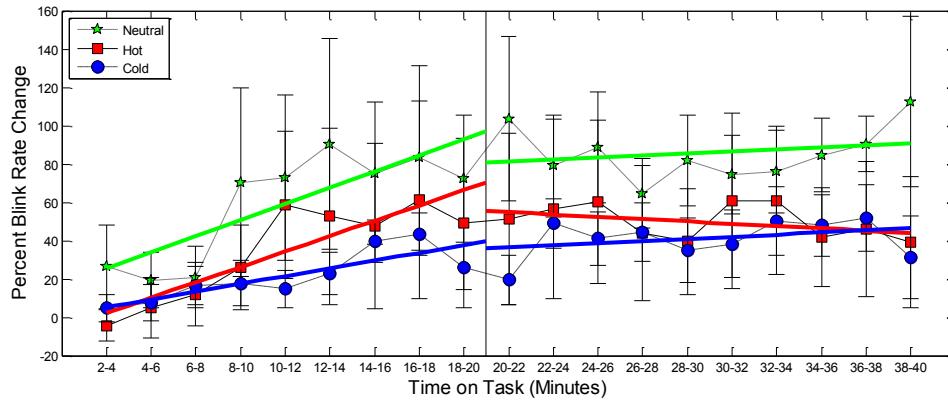
Figure B 12. Mean percent blink rate change over time on task. Eye measures are based upon percent change relative to baseline. The vertical lines indicated when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

A repeated measures ANOVA with a Greenhouse-Geisser correction indicated there was a significant effect between time periods for percent interblink interval change; $F(3.907, 39.067) = 3.899$, $p = 0.010$. Post hoc tests using the Bonferroni correction revealed that there was significant difference from period 2, 4 – 6 minutes and period 12, 24 – 26 minutes ($p = 0.049$), and period 2 and period 17, 34 – 36 minutes ($p = 0.039$). The data is displayed in Figure B 13. Trend lines in the figure show a decrease in interblink interval over the first 20 minutes. Participants on average blinked more and thus had less time between blinks. After the temperature change, the trend lines show an inversely consistent results with blink rate, interblink intervals for the hot condition increase while they decrease for the neutral and cold conditions. A Pearson product-moment correlation was run to determine if there was a relationship between percent correct detections and either eye measure. No significant correlation was determined.

50
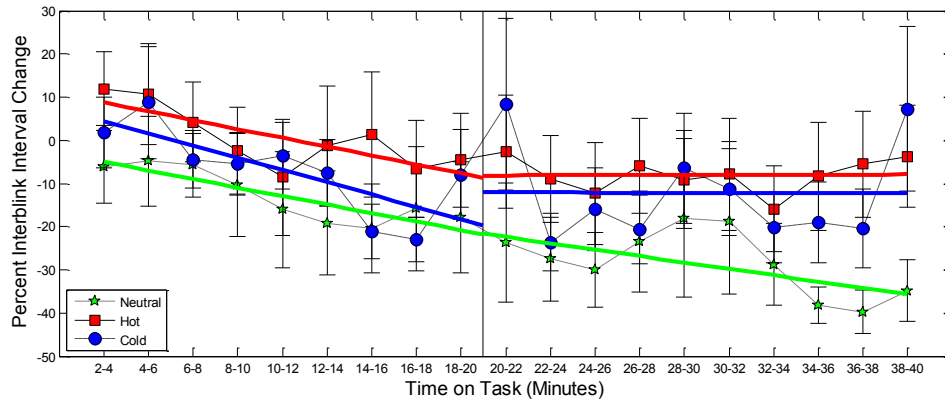
Figure B 13. Mean percent interblink interval change over time on task. Eye measures are based upon percent change relative to baseline. The vertical lines indicated when the temperature change occurred. Bold lines indicated linear trends and error bars indicate plus and minus one standard error of the mean.

Correlations with Vigilance.

A Pearson product-moment correlation was run to determine if there was a relationship between vigilance, or percent correct detections (hit rate) and any of the physiology measures. The correlation tables are displayed in Tables B 1 and B 2. A significant correlation between the percent correct detection and percent rSO_2 change values was found for both the hot (left: -0.533 and right: -.526) and cold (left: -.746 and right: -.738) conditions. Additionally, there was significant correlation between percent CVRR change and percent correct detections, for both the hot (-.536) and the cold conditions (.525) No significant correlations with percent correct detections for any of the physiology measures was determined for the neutral condition.

Table B 1. Hot condition correlation table. * indicates correlation values that are significant at the 0.05 level (2 – tailed).

	Hit Rate	Left rSO$_2$	Right rSO$_2$	Heart Rate	CVRR	Blink Rate	Interblink Interval
Hit Rate	1						
Left rSO$_2$	-.533*	1					
Right rSO$_2$	-.526*	.989*	1				
Heart Rate	-.181	.708*	.669*	1			
CVRR	-.536*	.213	.255	-.018	1		
Blink Rate	-.406	.069	.158	-.236	.501*	1	
Interblink Interval	.371	-.371	-.435	-.014	-.513*	-.583*	1

Table B 2. Cold condition correlation table. * indicates correlation values that are significant at the 0.05 level (2 – tailed).

	Hit Rate	Left rSO$_2$	Right rSO$_2$	Heart Rate	CVRR	Blink Rate	Interblink Interval
Hit Rate	1						
Left rSO$_2$	-.746*	1					
Right rSO$_2$	-.738*	.990*	1				
Heart Rate	-.012	.468*	.491*	1			
CVRR	.525*	-.810*	-.822*	-.319	1		
Blink Rate	.432	-.632*	-.680*	-.430	.647*	1	
Interblink Interval	-.071	.273	.317	.210	-.464*	-.840*	1

Discussion

Given that the advancement and increased complexity of systems has changed the role of the individual from active involvement to passive supervision within select fields; the need to maintain attention or vigilance over prolonged periods of time has become critical for success (Parasuraman and Riley, 1997; Warm, Parasuraman, and Matthews 2008; De Joux, Russell, and Helton, 2013). This requirement has found its way into the jobs of air traffic controllers, unmanned aerial system operators, TSA inspectors, and medical screening technicians (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2001). Therefore, determining a method to monitor the sustained attention of these individuals and intervene when a vigilance decrement occurs could improve overall task performance and reduce errors.

Vigilance Performance.

Performance scores or the percent of correct detection of critical signals identified by the participants was above 65 percent on average throughout the task. Initially a performance decrement was experienced across all three conditions; however, as a temperature change occurred, participants in each condition showed a different effect. Individuals in the neutral condition interestingly increased their performance, ending with detection rates greater than participants in the temperature change conditions and even their initial time periods. This dramatic increase with no known cause could be a result of additional learning or change of strategy by the participants. On average participants that experienced one of the two temperature changes showed an initial increase due to a cueing effect. This is consistent with a number of previous studies that have shown auditory or visual cues positively affecting vigilance performance (Hitchcock et al., 2002;

Pattyn et al., 2008). As the task continued performance of participants in the hot condition again showed a decline over time; however, the performance of participants in the cold condition showed an increasing trend.

Vigilance performance here and as studied previously along with other task types, is temperature dependent. Participants were in an enclosed pod surrounded by a thermoelectric pad and blanket, helping to retain their body heat and decrease air circulation to the skin. Those who received the neutral condition or the cold condition experienced temperatures at room temperature (68-81°F) and 65 °F, respectively. These temperatures fall near the optimal performance range, temperatures ranging from approximately 70 to 80 °F, found in previous research (Pilcher, Nadler, and Busch, 2002; Seppanen, Fisk, and Lei, 2006). Participants that received the hot condition, experience a temperature of approximately 110 °F, considerably higher than this range, thus leading to decreased performance.

Cerebral Oximetry.

Cerebral oxygen saturation (rSO_2) levels during the first 20 minutes of the experiment show an overall decreasing trend consistent with available mental resources reaching maximum capacity as demonstrated in previous studies (Hitchcock et al., 2003; Helton and Warm, 2008). After the initial period, one of three temperature change conditions is applied to all participants and the effects are clearly seen in the cerebral oximetry data output. rSO_2 values of participants that experienced the neutral condition, continued to decline over time on task and interestingly a greater separation was seen between the left and right hemisphere percent change values then either of the other conditions. Comparing the cerebral oximetry data with the performance results, the

separation could be explained by the considerable increase in percent correct detections displayed by the neutral condition group. Learning or change of strategy could have made the task easier resulting in fewer demands on the brain and thus less oxygen supply to the tissue (Bélanger, Allaman, and Magistretti, 2011).

rSO_2 values of participants that experienced the hot and cold conditions showed expected effects at the temperature change, the rSO2 values for the hot condition increased and the rSO2 values for the cold condition decreased. This effect was expected and is consistent with the known result that blood flow increases with increased body temperature and decreases with the reverse. As the time period containing the temperature change progressed however, both the hot and cold condition rSO_2 values increased. The increase in the hot condition values could be due to two possible effects, either the temperature change simply increased blood flow causing increased rSO_2 values or that it caused the participants additional stress and thus demands on the brain increased. For the cold temperature condition, the temperature change may have reduced concern by making the environment more comfortable and allowed for more focus on the task at hand.

Electrocardiography.

The electrocardiography (ECG) calculated measures also showed results in line with resource theory. Heart rate (HR) and heart rate variability (HRV) both changed over periods of watch. HR results showed a negative percent change initially from the baseline and then decreases further with time on task. After the temperature change at the 20 minute mark, participants' HR become less negative, as seen in Figure B 10 with the positive slopes of the trend lines. The heart rate of the participants that experienced

the hot condition showed the steepest positive slope, most likely due to increased blood flow. Those individuals in the cold condition also showed an increasing trend. Cold temperatures would be expected to decrease heart rate, thus this suggests that cooler temperatures in a more comfortable range improved the participants vigilance. Additionally, an addition of external input, the temperature change, to the body could have elevated participants stress and therefore their heart rates.

The component of heart rate variability (CVRR) inversely followed performance for the first 20 minutes across all three groups by decreasing on average over time. From the trend lines in the figures, it can be seen that after the temperature change, the neutral continued to increase, while the hot and cold conditions remained approximately constant. CVRR had a statistically significant negative correlation with vigilance performance for the hot condition. This agrees with previous research, that is, HRV has been shown to have inverse correlation with mental workload (De Waard, 1996; Rowe, Sibert, and Irwin, 1998). In contrast, CVRR had a statistically significant positive correlation with vigilance performance for the cold condition. No significant correlation was determined for the neutral condition.

Electrooculography.

Eye measures using electrooculography (EOG) additionally showed results consistent with a vigilance decrement. Blink rate of individuals significantly increased over time on task for the first 20 minutes for participants in all conditions. This is consistent with previous research stating that as vigilance declines blink rate increases (Langhals, Burgoon, Nunamaker, 2011; McIntire et al., 2011). After the temperature change, blink rates of participants in the neutral and cold condition continued to increase,

while blink rates for participants in the hot condition began to decrease. These trends are positively correlated with the performance trends, suggesting that the inverse blink rate may not always be indicative of performance.

Finally, interblink intervals were analyzed and decreased over the first 20 minutes of the experiment. Participants started to blink more and thus had less time between blinks as the vigilance task progressed. After the temperature change mark, participants in the neutral and cold conditions continued to have less time between blinks. Participant that experienced the hot condition showed an increase in interblink interval; however, the slope of the line was near zero suggesting little change in time between blinks.

Conclusion

The results from this 40-minute vigilance study add evidence to the field of vigilance research, particularly providing research to enable counter measures to be deployed. Ideally, the deployment of such countermeasures will permit the user to achieve greater success during tasks and activities requiring sustained attention. A variety of characteristics such as duration length, type of task, event rates, and modality could have had an effect on the results of this study; however, the physiology findings were similar to previous research and pointed to the resource model theory of vigilance. A vigilance decrement was present over time on task and participant performance varied as a function of change in localized temperature during the experiment. When participants were experiencing temperatures near the ideal range, approximately 70 to 80 ˚F, they achieved better performance scores. Cerebral oximetry is dependent on blood flow to the brain and effects of temperature change were present in this experiment;

57

however, there was still a significant correlation between both the left and right rSO_2 values and percent correct detections, regardless of temperature condition. Heart rate measures changed over time; however, no significant effect was discovered. CVRR was correlated with the vigilance decrement throughout the experiment in both the hot and cold temperature conditions. Finally blink rate increased during the initial performance decrement, but over time, the effect reversed and blink rate change was negatively correlated with changes in performance. As a result, cerebral oximetry and CVRR appear to reflect changes in performance better than just heart rate, blink rate or interblink intervals. Additionally, the results support the hypothesis that temperature changes could be employed to either cue the individuals of critical events or provide means to regulate the environment within an optimal range.

Acknowledgements

References

Beam, Christina Ashley. *Effects of Sensory and Cognitive Vigilance Tasks on Cerebral Blood Flow Velocity*. Diss. University of Cincinnati, 2002.

Bélanger, Mireille, Igor Allaman, and Pierre J. Magistretti. "Brain energy metabolism: focus on astrocyte-neuron metabolic cooperation." *Cell metabolism* 14.6 (2011): 724-738.

Bursill, A. E. "The restriction of peripheral vision during exposure to hot and humid conditions." *Quarterly Journal of Experimental Psychology* 10.3 (1958): 113-129.

Davies, P., and I. Maconochie. "The relationship between body temperature, heart rate and respiratory rate in children." *Emergency Medicine Journal* 26.9 (2009): 641-643.

De Joux, Neil, Paul N. Russell, and William S. Helton. "A functional near-infrared spectroscopy study of sustained attention to local and global target features." *Brain and cognition* 81.3 (2013): 370-375.

De Waard, Dick. *The measurement of drivers' mental workload*. Groningen University, Traffic Research Center, 1996.

Etnier, Jennifer L., et al. "The Influence of Physical Fitness and Exercise Upon Cognitive Functioning: A Meta-Analysis." *Journal of Sport & Exercise Psychology* 19 (1997): 249-277.

Funke, Matthew E., et al. "A comparison of cerebral hemovelocity and blood oxygen saturation levels during vigilance performance." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Vol. 54. No. 18. SAGE Publications, 2010.

Glaser, E. M., and R. J. Shephard. "Simultaneous experimental acclimatization to heat and cold in man." *The Journal of physiology* 169.3 (1963): 592-602.

Helton, William S., et al. "Cerebral lateralization of vigilance: a function of task difficulty." *Neuropsychologia* 48.6 (2010): 1683-1688.

Helton, William S., Ulrike Ossowski, and Sanna Malinen. "Post-disaster depression and vigilance: a functional near-infrared spectroscopy study." *Experimental brain research* 226.3 (2013): 357-362.

Helton, William S., and Joel S. Warm. "Signal salience and the mindlessness theory of vigilance." *Acta psychologica* 129.1 (2008): 18-25.

Helton, William S., et al. "The abbreviated vigilance task and cerebral hemodynamics." *Journal of Clinical and Experimental Neuropsychology* 29.5 (2007): 545-552.

Helton, William S., and Paul N. Russell. "Working memory load and the vigilance decrement." *Experimental brain research* 212.3 (2011): 429-437.

Hitchcock, Edward M., et al. "Automation cueing modulates cerebral blood flow and vigilance in a simulated air traffic control task." *Theoretical Issues in Ergonomics Science* 4.1-2 (2003): 89-112.

Langhals, Brent, Judee K. Burgoon, and Jay F. Nunamaker. *Using eye and head based psychophysiological cues to enhance screener vigilance*. Diss. University of Arizona, 2011.

Mackworth, N. H. "The breakdown of vigilance durning prolonged visual search." *Quarterly Journal of Experimental Psychology* 1.1 (1948): 6-21.

McIntire, Lindsey, et al. *Eye-Tracking: An Alternative Vigilance Detector*. INFOSCITEX CORP DAYTON OH, 2011.

Molloy, Robert, and Raja Parasuraman. "Monitoring an automated system for a single failure: Vigilance and task complexity effects." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 38.2 (1996): 311-322.

Oken, B. S., M. C. Salinsky, and S. M. Elsas. "Vigilance, alertness, or sustained attention: physiological basis and measurement." *Clinical Neurophysiology* 117.9 (2006): 1885-1901.

Oldfield, Richard C. "The assessment and analysis of handedness: the Edinburgh inventory." *Neuropsychologia* 9.1 (1971): 97-113.

Parasuraman, Raja, and Victor Riley. "Humans and automation: Use, misuse, disuse, abuse." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 39.2 (1997): 230-253.

Pattyn, Nathalie, et al. "Psychophysiological investigation of vigilance decrement: boredom or cognitive fatigue?." *Physiology & Behavior* 93.1 (2008): 369-378.

Pilcher, June J., Eric Nadler, and Caroline Busch. "Effects of hot and cold temperature exposure on performance: a meta-analytic review." *Ergonomics* 45.10 (2002): 682-698.

Poulton, E. C., N. B. Hitchings, and B. BROOKE. "Effect of cold and rain upon the vigilance of lookouts." *Ergonomics* 8.2 (1965): 163-168.

Rowe, Dennis W., John Sibert, and Don Irwin. "Heart rate variability: Indicator of user state as an aid to human-computer interaction." *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM Press/Addison-Wesley Publishing Co., 1998.

See, Judi E., et al. "Meta-analysis of the sensitivity decrement in vigilance." *Psychological Bulletin* 117.2 (1995): 230.

Seppanen, Olli, William J. Fisk, and Q. H. Lei. "Effect of temperature on task performanFce in office environment." *Lawrence Berkeley National Laboratory* (2006).

Stevenson, Hugh, Paul N. Russell, and William S. Helton. "Search asymmetry, sustained attention, and response inhibition." *Brain and cognition* 77.2 (2011): 215-222.

Teichner, Warren H. *Predicting Human Performance III: Detection of a Simple Visual Signal as a Function of Time of Watch*. No. NMSU-ONR-TR-72-1. NEW MEXICO STATE UNIV LAS CRUCES DEPT OF PSYCHOLOGY, 1972.

Temple, Jon G., et al. "The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 42.2 (2000): 183-194.

Warm, Joel S., Raja Parasuraman, and Gerald Matthews. "Vigilance requires hard mental work and is stressful." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50.3 (2008): 433-441.

IV. Conclusions and Recommendations

Chapter Overview

Chapter 5 is an overall summary of this research endeavor, starting with the purpose and goals and ending with the results and discussion of the data collected. The investigative questions from Chapter 1 are revisited and answered in coordination with the findings presented in the two articles. The significance of this study in the field of vigilance research will be discussed and recommendations for future research will be offered.

Research Overview

This research investigated the effect of localized temperature changes on vigilance performance and corresponding changes in physiology measures. The presence of a vigilance decrement has been well documented; however, methods for aiding users to overcome this decrement are still in development. A human-subject experiment was developed in conjunction with a student from Wright State that looked to understand vigilance and the effects of localized temperature changes. The experiment entailed completion of a 40-minute simulated air traffic control vigilance task, in which participants had to detect critical signals displayed at random. Three localized temperature condition changes, a positive, negative, or no change, were randomly assigned to participants and administered at the halfway point of the task. Throughout the experiment three physiology measures, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) were collected. The results suggest that physiology measures can be used to determine the state of an individual during a

vigilance task; however, caution must be taken when interpreting the results due to the variety of differences present between individual's physiology. An initial vigilance decrement was present on average across participants during the first 20 minutes of the experiment. After the halfway point, localized temperature changes within a comfortable range improved performance. Left and right cerebral oxygen saturation values and heart rate variability correlated with changes in vigilance and could be used as possible detection measures.

Answers to Investigative Questions

Question 1: What physiological measures can be used to easily and accurately measure a vigilance decrement?

Previous research has conducted a number of studies using physiology measures that have included a range of techniques such as analyzing facial expressions, brain blood supply, movements of eye anatomy, heart rate, and breathing rate. During this experimental session three of the most popular measures, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) measures were used because they were easy to administer and provided accurate data for analysis. Specifically, cerebral oxygen saturation (rSO_2) values, heart rate, one component of heart rate variability, the coefficient of variation of R-R (CVRR), blink rate, and interblink intervals were gleamed from the raw data. All of these physiology measures except heart rate showed a significant effect with performance over time on task. The left and right cerebral oxygen salutation (rSO_2) values and CVRR were the only measures that showed a significant correlation with vigilance. Finally Blink rate and interblink interval were

expected to provide more significant findings; however, the performance signal display rate of 30 displays per minute may have affected how often participants blinked.

Question 2: How do these physiological measures compare with previous research?

While a variety of characteristics such as duration length, type of task, event rates, and modality are different in each vigilance task, the physiology findings were similar to previous research and pointed to the resource model theory of vigilance. rSO_2 values initially increased suggesting that increased processing demands on the brain called for increase oxygen supply to the tissue. As mental resources reached their capacity and vigilance began to decline, rSO_2 values decreased as well. The heart rate measures followed a similar trend during the first 20 minutes of the experiment. Blink rate remained fairly constant during the beginning few periods of time and then considerably increased 8 to 14 minutes around the time that performance showed a decrease. As participants became overloaded, they may have began to blink more to remain awake and focused on the task.

Question 3: How do changes in temperature affect human performance on vigilance tasks?

According to the results of this study, when participants were experiencing temperatures near the ideal range, approximately 70 to 80 ˚F, they achieved better performance scores. This was shown with most participants during the first 20 minutes of the experiment and then with those in the neutral and cold conditions during the remainder of the time. Cerebral oximetry is dependent on blood flow to the brain and effects of temperature on cerebral oximetery were present after a positive or negative

temperature change; however, there was still a significant correlation between both the left and right rSO_2 values and percent correct detections. Heart rate measures changed significantly over time and were indicative of the vigilance decrement during the first 20 minutes. During the second half of the experiment, heart rate trends of the participants for both the hot and cold condition began to increase, suggesting additional stress due to tactile input. Heart rate variability, specifically the CVRR component, was significantly correlated with vigilance throughout the experiment.   Finally blink rate was not believed to be directly affected by increases in temperature.   Blink rate increased during the initial performance decrement, but after the temperature change, the effect reversed and blink rate change matched changes in performance.

Significance of Research

Given that the advancement and increased complexity of systems has changed the role of the individual from active involvement to passive supervision within select fields; the need to maintain attention or vigilance over prolonged periods of time has become critical for success (Parasuraman and Riley, 1997; Warm, Parasuraman, and Matthews, 2008; De Joux, Russell, and Helton, 2013). This requirement has found its way into the jobs of air traffic controllers, unmanned aerial system operators, TSA inspectors, and medical screening technicians (Warm, Parasuraman, and Matthews, 2008; McIntire et al., 2011).   Therefore, determining a method to monitor the sustained attention of these individuals and intervene when a vigilance decrement occurs could improve overall task performance and reduce errors. The results from this 40-minute vigilance study can add further information to the field of vigilance research by being able to identify a vigilance

65

decrement in individuals using a variety of physiology measures to enable counter measures to be deployed. Ideally, the deployment of such countermeasures will permit the user to achieve greater success during tasks and activities requiring sustained attention.

Recommendations for Future Research

While this research was able to provide further insight into factors affecting vigilance performance and identify physiology measures that can be beneficial for understanding the attentional state during a vigilance task, there are still areas to be investigated further.

One recommendation for future research with vigilance task is to provide more thorough training prior to the task to make sure all participants are well practiced on the task. This would reduce fluctuations in the performance scores and hopefully reduce any learning effects that may have been present in this research study.

Another suggestion for additional experiments is to examine temperature changes more thoroughly. Different temperatures could be examined in a steady state environment where participants remain at different but constant temperature throughout the duration of the vigilance task. In contrast, temperature changes could be examined as a cueing mechanism to alert individuals that their performance has decline below some threshold.

Physiology measures could play a more active part of the experiment and provide a triggering mechanism for the temperature changes. Real time analysis and feedback from the physiology measures would be necessary. This adaptive automation would

allow the system to tune into the individual's attentional state and work to perform the necessary countermeasures at the appropriate time.

Summary

The current research was able to use human subject testing to identify physiology measures that correlate with vigilance. Cerebral oxygen saturation (rSO_2) values determined from cerebral oximetry and one component of heart rate variability, CVRR, recorded using electrocardiography can be used as monitors of attention states for operators during vigilance tasks. Through integration of these results, better and more reliable interactive vigilance displays and compensatory measures may be developed.

References

Ballard, Joan C. "Computerized assessment of sustained attention: a review of factors affecting vigilance performance." *Journal of clinical and experimental neuropsychology* 18.6 (1996): 843-863.

De Joux, Neil, Paul N. Russell, and William S. Helton. "A functional near-infrared spectroscopy study of sustained attention to local and global target features." *Brain and cognition* 81.3 (2013): 370-375.

Enander, Ann E. "Effects of thermal stress on human performance." *Scandinavian journal of work, environment & health* 15 (1988): 27-33.

Helton, William S., and Joel S. Warm. "Signal salience and the mindlessness theory of vigilance." *Acta psychologica* 129.1 (2008): 18-25.

Helton, William S., et al. "The abbreviated vigilance task and cerebral hemodynamics." *Journal of Clinical and Experimental Neuropsychology* 29.5 (2007): 545-552.

McIntire, Lindsey, et al. *Eye-Tracking: An Alternative Vigilance Detector*. INFOSCITEX CORP DAYTON OH, 2011.

Molloy, Robert, and Raja Parasuraman. "Monitoring an automated system for a single failure: Vigilance and task complexity effects." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 38.2 (1996): 311-322.

Parasuraman, Raja, and Victor Riley. "Humans and automation: Use, misuse, disuse, abuse." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 39.2 (1997): 230-253.

See, Judi E., et al. "Meta-analysis of the sensitivity decrement in vigilance." *Psychological Bulletin* 117.2 (1995): 230.

Stevenson, Hugh, Paul N. Russell, and William S. Helton. "Search asymmetry, sustained attention, and response inhibition." *Brain and cognition* 77.2 (2011): 215-222.

Teichner, Warren H. *Predicting Human Performance III: Detection of a Simple Visual Signal as a Function of Time of Watch*. No. NMSU-ONR-TR-72-1. NEW MEXICO STATE UNIV LAS CRUCES DEPT OF PSYCHOLOGY, 1972.

Temple, Jon G., et al. "The effects of signal salience and caffeine on performance, workload, and stress in an abbreviated vigilance task." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 42.2 (2000): 183-194.

Warm, Joel S., Raja Parasuraman, and Gerald Matthews. "Vigilance requires hard mental work and is stressful." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50.3 (2008): 433-441.

Appendix A – IRB Approval

1 7 OCT 2013
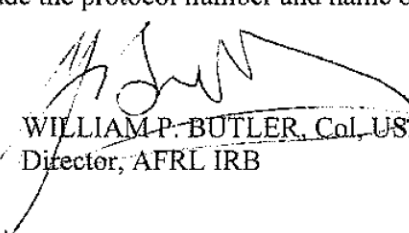
MEMORANDUM FOR AFIT/ENV (MICHAEL E. MILLER, PhD)

FROM: 711 HPW/IR (AFRL IRB)

SUBJECT: IRB approval for the use of human volunteers in research

1. Protocol title: Examining Localized Temperature Changes and Vigilance Performance

2. Protocol number: FWR20130209H

3. Protocol version: 1.00

4. Risk: Minimal

5. Approval date: 17 October 2013

6. Expiration date: 16 October 2014

7. Scheduled renewal date: 17 September 2014

8. Type of review: Initial – Expedited

9. Assurance Number and Expiration Date:
   - AFRL DoD Assurance 50002: 14 March 2014
   - Infoscitex FWA00008359, DoD Addendum F50339: 1 February 2017

10. CITI Training: Completed

11. The above protocol has been reviewed and approved by the AFRL IRB via expedited review procedures. All requirements, as set by the IRB and its legal counsel, have been fully complied with. The study seeks to determine the effect of localized temperature changes on vigilance performance and whether individual stress appraisals moderate the relationship between localized temperature changes and vigilance performance. Physiologic measurements will also be collected (eg, electrocardiography, electrooculography, and cerebral oximetry). The study is minimal risk. This protocol therefore meets the criteria for expedited review in accordance with 32 CFR 219.110 (b)(1) and U.S. Department of Health and Human Services category (7): Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

12. HIPAA authorization is not required, since no HIPAA protected information will be recorded in the execution of this protocol.

13. FDA regulations do not apply since no drugs, supplements, or unapproved medical devices will be used in this research. The color vision screening devices are themselves, as utilized in this study, non-significant risk devices.

14. This approval applies only to the requirements of 32 CFR 219, DoDD 3216.2, AFI 40-402, and related human research subject regulations. If this project is a survey, attitude or opinion poll, questionnaire or interview, consult AFI 38-501, AF Survey Program, for further guidance. Headquarters AFPC/DPSAS is the final approval authority for conducting attitude and opinion surveys within the Air Force. If the survey, attitude or opinion poll, questionnaire or interview is hosted on a .com server, consult AFI 33-129, Web Management and Effective Use of Internet-based Capabilities, for further guidance. If the study is being conducted under an Investigational New Drug (IND) or Device Exemption (IDE), a copy of the FDA IDE or IND approval letter must be submitted by the Principal Investigator to the IRB.

15. With this approval comes the expectation that the Principle Investigator has the funding to fully execute the protocol. Partial protocol funding, particularly with Greater than Minimal Risk studies, should prompt a re-examination of the protocol by both the Principle Investigator and the IRB with specific emphasis on the risk-benefit evaluation.

16. Any serious adverse event or issues resulting from this study should be reported immediately to the IRB. Amendments to protocols and/or revisions to informed consent documents must have IRB approval prior to implementation. Please retain both hard copy and electronic copy of the final approved protocol and informed consent document.

17. All inquiries and correspondence concerning this protocol should include the protocol number and name of the primary investigator. Please ensure the timely submission of all required progress and final reports and use the templates provided on the AFRL IRB web site http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=7496 .

18. For questions or concerns, please contact the IRB administrator, Lt Amands Hull at amanda.hull@wpafb.af.mil or (937) 904-8094. All inquiries and correspondence concerning this protocol should include the protocol number and name of the primary investigator.
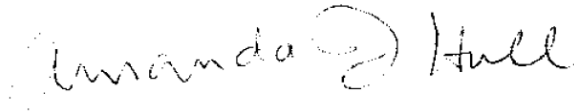
WILLIAM P. BUTLER, Col, USAF, MC, CFS
Director, AFRL IRB

cc:
AFMSA/SGE-C

71

1st Indorsement to AFIT/ENV (MICHAEL E. MILLER, PhD) Memo, 17 October 2013, Initial Review expedited approval FWR20130209H

MEMORANDUM FOR 711 HPW/IR (KIM LONDON)

I have reviewed the hardcopy and electronic records and found them to be complete and accurate.
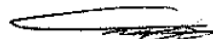
AMANDA J. HULL, 1Lt, USAF
Lead Administrator, AFRL IRB

2nd Indorsement to AFIT/ENV (MICHAEL E. MILLER, PhD) Memo, 17 October 2013, Initial Review expedited approval FWR20130209H

MEMORANDUM FOR AFMSA/SGE-C

This protocol has been reviewed and approved by the AFRL IRB. I concur with the recommendation of the IRB and approve this research.

1 8 UL1 2013

TIMOTHY T. JEX
Brigadier General, USAF, MC, CFS
Commander
711th Human Performance Wing

Title of Investigation – Examining Localized Temperature Changes and Vigilance Performance

1. **Principal Investigator**
     a. Michael E. Miller/Ph.D/Assistant Professor, AFIT/ENV, (937) 255-3636 x4651, Michael.Miller@afit.edu

2. **Associate Investigators**
     a. Justine D. Jeroski/Master's Student, AFIT/ENV, Justine.Jeroski@afit.edu
     b. Jessica S. Pack/Master's Student, 711HPW/RHCI, Infoscitex, (937) 713-7172, Jessica.Pack.ctr@wpafb.af.mil

3. **Medical Consultant**

   TSgt Bethany Repp, USAF AFMC 711 HPW/RHCPT, (937)-938-3702, Bethany.Repp@wpafb.af.mil, 2510 Fifth Street, Bldg. 840

4. **Facility/Contractor**
   Testing will occur in RH's collaborative workspace, Room 023, Building 33.

   Contractor support will be provided by Infoscitex,

   Testing will be conducted in support of AFRL's Thermal Science and Technology Team (STT).

   Testing will be conducted in support of the Air Force Institute of Technology (AFIT) System Engineering Program

5. **Conflicts of Interest**
   None

6. **Objective**
   The aim of this study is to determine the effect of localized temperature changes on vigilance performance and whether individual stress appraisals moderate the relationship between localized temperature changes and vigilance performance. Electrocardiography, electrooculography, and cerebral oximetry data will be measured during a vigilance task to determine the relationship between these physiological measures, temperatures changes, and human performance.

7. **Background**
   Sustained vigilance has become increasingly important in modern work places as more human work involves automated human-machine systems (Warm, 1977). Machines are now primarily performing tasks that once had to be performed by humans. The technological advances, leading to automated machines, have changed the role of operators from hands-on controllers to passive supervisors, in which action

73

is required only when a problem arises (Sheridan, 1970). As a result of this shift, vigilance has become a crucial element of human performance in careers that use automated machines, such as air traffic control, military surveillance, airport baggage inspection, and robotic manufacturing (Hancock & Hart, 2002; Satchel, 1993; Warm, 1984). Although automated human-machine systems have obvious benefits in the work place, their introduction has created additional problems related to over-reliance and sustained vigilance (Molloy & Parasuraman, 1996). Whereas it is relatively easy for people to be briefly attentive to a series of predictable events, maintaining attention to unpredictable events over a long period of time is difficult, especially when the events also have a low probability of occurrence. A stream of research has demonstrated that signal detection during a vigilance task markedly declines over time (e.g., Mackworth, 1950). This phenomenon, known as the vigilance decrement, results from a decrease in arousal brought on by under stimulation (Mackworth, 1948). Whereas concern for vigilance is not new, little research exists regarding the relationship between temperature and vigilance. The research that does exist on the relationship is conflicting, and it focuses more on static ambient temperature, rather than localized temperature changes. The purpose of this study is to determine the effects of localized temperature change on vigilance performance along with individual stress appraisals. Further the study will seek to understand the relationship between physiology measures and the vigilance decrement.

Several theories regarding the cause of the vigilance decrement exist. The arousal theory of vigilance operates under the idea that vigilance decreases as a subject's arousal level decreases (Parasuraman, 1985). The term arousal is defined by most researchers as a varying state of alertness, ranging from deep sleep to wide awake (Humphreys & Revelle, 1984; Matthews & Davies, 1998). Research has suggested that sensory input is required in humans in order to maintain alertness (Hebb, 1958). Further, a subject will become under-aroused if input variation stays above a certain level. This drop in arousal results in the vigilance decrement (Parasurman, 1985). More recent research has challenged this view and has instead proposed that maintaining vigilance imposes high stress and a substantial demand on the mental resources of the observer (Warm, Parasuraman, & Matthews, 2008).

A number of altering techniques, such as exercise and drugs, were successful in increasing vigilance performance but these techniques have limitations. Exercise at a workstation is not always possible and drugs can have unwanted side effects (Warm, Dember, & Parasurman, 1991). This study has chosen to examine localized temperature change as an altering technique because it is easy to regulate within a workspace and has few possible adverse side effects. Additionally, the research studying the relationship between temperature and vigilance up to this point is limited, and the results are conflicting. Mackworth (1948) found after testing subjects under ambient temperatures of 70° F, 79° F, 87.5° F, and 97° F that performance was superior at 79° F. In contrast, Pepler (1953) found that subjects performed better at 67° F and 97° F than at 82° F. Bursill (1958) also conducted a series of experiments studying the relationship between temperature and vigilance. He found that overall

high ambient temperatures resulted in a greater vigilance decrement than low ambient temperatures. Similar results were reported by Poulton, Hitchings, and Brooke (1965), who found quicker reaction times in colder environments. A more recent study found that body temperature was associated with changes in human performance, even after controlling for the effects of the circadian phase and hours awake. More specifically, cognitive performance was superior when body temperature was higher regardless of the time of day (Wright, Hull, & Czeisler, 2002).

While many physiological measures of the vigilance decrement have been examined and analyzed, there has been no agreement on a preferred method that clearly identifies loss of vigilance in every individual and in a variety of situations. Additionally, environmental factors such as temperature changes have been considered to either facilitate or interfere with human performance depending on the level of stress a particular variable causes. Adding to the current knowledge base on determining vigilance loss by further assessing the sensitivity and diagnosticity of three physiology measures, electrocardiography, electrooculography, and cerebral oximetry, this research will look to quantifiably determine when vigilance is lost and the effects of positive and negative temperature changes on human performance.

The first physiology measure, an electrocardiogram (ECG), is a measure of an individual's heart rate and has been used in numerous studies to assess mental workload (Aasman, Mulder, & Mulder, 1987, Rowe, Siber, & Irwin 1998). Specifically heart rate variability (HRV) has been shown to change inversely with metal workload (Rowe, Siber, & Irwin 1998). Monitoring heart rate data during a vigilance task could therefore help to understand the amount of mental effort and whether the vigilance decrement is due to low mental effort (arousal theory) or instead due to a high mental effort (resource theory) (Warm, Parasuraman, & Matthews, 2008).

An electrooculogram (EOG) is a technique for measuring the resting potential of the muscles which control the rotation of the human eye and thus changes in potential can be applied to determine eye movements such as saccadic movements, fixations, and eye blinks. Based on previous research, these eye movements have been shown to be indicative of vigilance decline over time (McIntire et al, 2011, Langhals, Burgoon, & Nunamaker, 2011). Using EOG data in addition to ECG data will help to further quantify the vigilance decrement and allow for a comparison between the two measures. Specifically, while it is reasonable to expect that heart rate will vary as a function of temperature, regardless of mental state, a strong relationship between eye movements and temperature is not expected (Glaser & Shephard 1963, Davies & Maconochie, 2009).

Finally, cerebral oximetry (CO) is an important measure to examine when trying to understand the vigilance decrement and temperature effect upon performance. Cerebral oximetry measures cerebral oxygenation values using near-infrared

spectroscopy technology. Studies have used this measure to quantify the vigilance decrement and while there were some mixed results due to a variety of other possible experimental factors, many have found that a decline in vigilance is paralleled with a decline in cerebral blood flow velocity (Warm, Matthews & Parasuraman, 2009). Additionally greater activity in the right than the left cerebral hemisphere was seen (Helton et al, 2007, Warm, Matthews & Parasuraman, 2009). This study will use this measure in conjunction with the other two measures to examine the findings of previous research and help identify the effects of localized temperature changes on human performance.

This study will also investigate whether the relationship between localized temperature change and vigilance performance is moderated by individual stress appraisals. People appraise situations differently, and these differences make some people more vulnerable to poor stress outcomes than others (Blascovich & Tomaka, 1996; Schneider, 2004; Vollrath & Torgersen, 2000). Stressor appraisals result in challenge when a person believes they have adequate resources to meet situational demands, and threat when a person believes they do not have adequate resources to meet situational demands (Lazarus & Folkman, 1984). Past research has shown that people who are challenged perform better on tasks than those who are threatened (Tomaka et al., 1993; Schneider, 2004, 2008). Further, certain personality traits are known to uniquely predict an individual's stress response. Schneider et al. (2011) conducted a study that investigated the influence of three different personality traits, neuroticism, extraversion and openness, on stress responses. They found that neuroticism uniquely predicted higher threat appraisals, lower positive effect, and higher negative effect. Those high in neuroticism also performed worse on the stressful tasks, to the extent that they experienced higher threat appraisals. The finding that those high in Neuroticism perform worse on tasks particularly when they appraise the task as a threat converges with Schneider (2004). In contrast, openness and extraversion both predicted higher positive affect and lower negative effect. These results suggest that stable factors, such as personality traits, are linked to individual stressor appraisals, state affect, and task performance. Because appraisals predict performance robustly, we want to investigate whether they predict performance on a vigilance task. This study investigates whether individual stressor appraisals moderate the effects of localized temperature changes on vigilance performance.

As more workplaces rely on automated human-machine systems, sustained vigilance and the factors that affect vigilance has become increasingly important. Temperature is an environmental factor that is easily manipulated and can be feasibly implemented in workplaces. The results from this study will help to clear up the inconsistent research that currently surrounds the relationship between temperature and vigilance performance. The effects of temperature change, rather than static temperature, on vigilance will be investigated along with individual stress appraisals.

8. **Impact**

76

Investigating the relationship between localized temperature changes and vigilance performance is important to those positions in the Air Force that require sustained vigilance. If a significant effect is observed between localized temperature change and vigilance performance then the introduction of temperature changing devices, such as chairs or vests, in the work place could increase the amount of time workers are able to stay vigilant. Air traffic controllers could potentially work longer shifts without seeing a decrease in vigilance over time.

9. **Experimental Plan**
   a. Equipment:
   Pod: Subjects will be seated in a pod while they perform a simulated air traffic control vigilance task (Metronaps). The pod is 212.19 cm long, 145.73 cm tall, and the dome of the pod is 121.91 cm wide. The entire pod, including the base, weighs 310 lbs. The shield built into the pod will function to prevent subjects from becoming distracted by outside stimuli (see figure 1).

   Thermoelectric Pad and Blanket: A thermoelectric pad and thermoelectric blanket combination will be used during the study to manipulate the localized temperature of subjects while they sit in the pod (Tempronics). The thermoelectric pad will be placed in the seat of the pod and subjects will sit on the thermoelectric pad while covered by the thermoelectric blanket during the course of the study. Thermoelectric coils that can either heat or cool, depending on the direction of the current, are woven into the materials used to construct the thermoelectric pad and blanket. The thermoelectric pad and blanket have an operating range of 65°F to 110°F. Figure 1 shows the thermoelectric pad and blanket placed inside the pod with and without the shield closed on the pod. A safety permit was completed on both pieces of equipment (See Appendix F).

Figure 1. The thermoelectric pad and blanket situated inside the pod while the shield is open and closed.

   Electrocardiography: Subjects will also wear electrodes on their chest. These electrodes will be attached to a BIOPAC 150 with an electrocardiography (ECG) amplifier for measuring the electrical signals associated with the beat of the

human heart. This instrument is a research instrument that has been certified for conformity according to the applicable European Standard (EN)/International Electrotechnical Commission (IEC) standards as documented in the Conformity statement referred to in Appendix G.

Electrooculography: Subjects will also wear electrodes on both temples and forehead. These electrodes will be attached to a BIOPAC system to conduct electrooculography (EOG) which measures the movement of the eyes with respect to the head. This system records the potential difference between the two electrodes as the eye moves from the center, neutral position towards either of the electrodes. This instrument is a research instrument that has been certified for conformity according to the applicable EN/IEC standards as documented in the Conformity statement referred to in Appendix G.

Cerebral Oximeter: Subjects will also wear a sensor on the forehead. This sensor will be attached to a Somanetics Invos Cerebral Oximeter 5100C to conduct cerebral oximetry (CO), which continuously and noninvasively measures blood oxygen saturation using near-infrared spectroscopy technology. Specifically it measures oxygen in brain or tissues directly beneath the sensor using two wavelengths, 730 and 810 nm, to measure changes in regional oxygen saturation. The Somanetics Invos Cerebral Oximeter 5100C is cleared by the FDA to be safe and effective device (U.S. Food and Drug Administration).

Infrared Camera: A FLIR T400 Infrared Camera may be used throughout the experiments to take thermal images of the equipment and subjects. The camera outputs a heat map with a designated number of discrete temperature levels, as well as an average temperature within a designated area of interest. The camera laser pointer will not be used. Technical specifications are listed in Appendix I.

b. <u>Subjects</u>:

Fifty-four (Experiment 1) and twenty-four (Experiment 2) volunteer subjects will be enrolled in this study. Enrollment in this study will be limited to male and females between the ages of 18 and 45. Volunteers must have normal or corrected-to-normal visual acuity and depth perception. No monetary compensation is being offered for participation in this study. Volunteers will be recruited through email by the researchers and sent out to the AFRL, AFIT, and/or AFLCMC/EZ listservs (See Appendix H).

Using a 2-tailed alpha = .05 and Power = .80, the sample size was estimated from past research on challenge or threat responses during distress (Schneider, 2004). Challenge and threat groups had different negative emotional experiences just after learning about task performance (Mean difference= .78; Effect Size d= 1.54) and different negative emotional experiences after the task (Mean difference= .89; Effect Size d= 1.21), requiring at least 16 and 12 participants per group,

respectively. Challenge and threat groups also exhibited differences in task performance (math performance) (Mean Difference= 9.4; Effect Size d= .66), requiring at least 38 participants per cell. However, there were approximately 15 responses on average across the task, which lacks the precision of the Hits, Misses, and False Alarms that will be recorded during the simulated air traffic control task. Past vigilance research has secured significant effects including sample sizes of 10 (Hitchcock, 2000; 2003). Utilizing the initial sample size estimates, 2 per group were added to account for potential equipment malfunction (Schneider, 2004; 2008). Thus the sample size for the first experiment (with survey data) will be 18 participants in each cell, requiring 54 participants total and the sample size for the second experiment (without survey data) will be only 12 participants per cell in 2 cells, requiring 24 participants total.

    c.   Duration:

The time requirement for each volunteer subject is anticipated to be one 90 minute session.

Total duration of the study will not last longer than 9 months.

    d.   Description of experiment, data collection, and statistical analysis:

Experiment 1 – Examining the effects of localized temperature changes on vigilance performance and stress appraisals + Understanding the relationship between ECG/EOG and vigilance performance

(1) Sensor Application: The subject will be fit with the ECG, EOG, and CO sensors for 5-10 minutes prior to the beginning of the task in order to calibrate the devices.

The ECG fitting requires the electrodes to be attached to the subject's chest and will require clothing which covers the upper torso to be lifted or removed to permit probe placement. This fitting will take place in a gender-consistent restroom with the assistance of an individual having the same gender as the subject. Once the electrodes are fit, the subject will be permitted to return their clothing to its proper position on their torso before leaving the restroom. After completion of the study, the subject will be asked to return to the restroom to remove the electrodes, clean any remaining contact gel and reposition any clothing.

(2) Calibration: The subject is fit with the ECG, EOG, and CO sensors and initial data will be taken to determine accurate signals are being detected. BIOPAC software will be used to record the ECG and EOG data and the INVOS system will be used for the CO data. The CO device has an automatic self-calibration

algorithm that confirms the quality of the signal and function of the sensors for each new subject.

(3) Cognitive Task: Subjects will engage in a 40-minute vigilance task run by a software package called Super Duper Lab in which subjects will monitor simulated air-traffic control displays. The simulated air-traffic control displays, consisting of three concentric circles with four arrows between the two outer most circles, will be displayed on different areas of a computer monitor throughout the 40-minute vigilance task. Subjects will be see 30 displays/min and each display will remain on the screen for 300ms. The configuration of the four arrows between the two outer most circles will change as the display is updated. Displays showing arrows aligned in a potential collision path are considered critical events and warrant an overt response from the subjects. In this study, subjects will indicate a critical event by pressing a clicker held in their dominant hand. Displays showing arrows aligned in a non collision path or safe path are considered neutral events and require no overt response from the subjects. Examples of possible critical event displays and neutral event displays are shown in Figure 2. The software package has been programmed to display 10 critical events randomly within each 10 minute portion of the 40 minute vigilance task (signal probability per period is 0.033). Studies by Hitchcock et al. (1999/2003) have repeatedly demonstrated the simulated air-traffic control task has sufficient sensitivity to detect the temporal decreases in performance associated with vigilance tasks.

Critical Event (Collision Path)
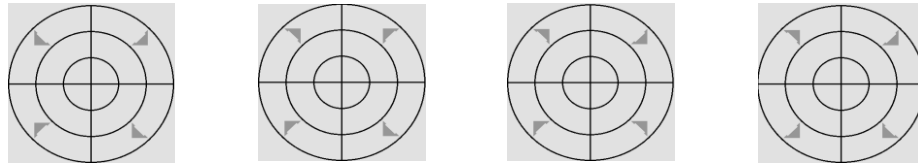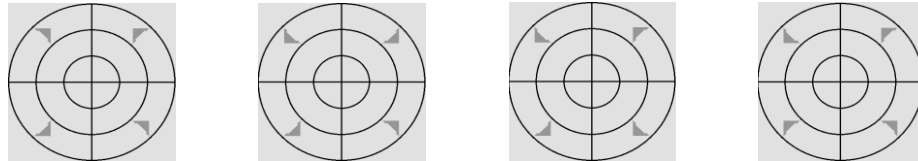
Clockwise Flight Paths

Counter-clockwise Flight Paths

Neutral Event (Safe) Stimuli
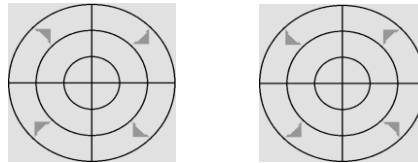
Figure 2. Possible critical event and neutral event displays from the simulated air traffic control vigilance task.

(4) Training: An in-depth description of the simulated air traffic control vigilance task will be read to subjects and examples of critical signals and neutral signals will be shown to them. Prior to data collection, subjects will have 5 minutes to practice the vigilance task while seated in the pod.

(5) Test Sessions and Testing Sequence: After arrival, the subjects will receive an introduction to the research team and a briefing on the study and its goals. The informed consent document will be explained and the subjects will be allowed to read it thoroughly. Any questions they may have will be answered and the subjects will then be directed to sign giving their consent. Each subject's name, age, gender, and contact information will be recorded and a unique number will be assigned to them. This link will be recorded in hardcopy only, stored in a locked cabinet, and destroyed post protocol completion. The number will remain with the data. Each subject will then be assessed for dominant hand by taking the Edinburgh Handedness Inventory (Appendix C). Normal visual acuity and depth perception are qualification prerequisites for this study. The researchers will be screening the subjects using two standard vision tests that only require minutes to administer, a 4 meter (13ft.) SLOAN Eye Chart (Precision Vision) and a TNO test

for stereoscopic vision (Laméris Instrumenten b.v.). No medical diagnosis will be offered and subjects who fail any vision screening will only be excluded from participating. Then an in-depth description of the simulated air traffic control vigilance task will be read to them and examples of critical and neutral signals will be shown to them. Volunteer subjects will be randomly assigned to a positive, negative, or neutral (control) temperature condition and a description of the basic experimental setup will be provided. Following this assessment, the subjects will be asked to fill out a ten-item stress appraisal scale questionnaire (Appendix D).

The subjects will be fit with the ECG, EOG, and CO sensors and enter the pod, sitting on top of the thermoelectric pad. The thermoelectric blanket will be placed over the body of the subject, allowing free range of their hands. The subjects will then be given a clicker to hold in their dominant hand, which they will use to indicate when a critical signal is observed during the vigilance task. A computer screen, placed inside the pod, in front of the subject, will display a start up screen for the vigilance task telling subjects to press the clicker when they are ready to start the task. Before data collection begins, subjects will have 5 minutes to practice the vigilance task. Any subjects who detect less than 60% of the critical signals or make more than 5 false alarms during this portion of the study will be excluded from the rest of the study.

Upon successful completion of the practice period, subjects will press the clicker to begin the 40 minute simulated air traffic control task. Software named Super Duper Lab will record the vigilance task results throughout the entire 40-minute session. Additionally, BIOPAC software will continue to record all of the ECG and EOG data and INVOS software for the CO data. The temperature changes, performance data, and physiological data will all be coupled within a single process to accurately keep the time scale consistent throughout the experiment. Depending on the condition assigned to each subject, after 20 minutes of working on the task the temperature of the pad and blanket will be increased to 110°F, decreased to 65°F, or remain the same temperature. If a subject is assigned to a negative or positive temperature change condition, then the entire temperature change will occur within 1 minute of the switch being flipped on the thermoelectric pad and blanket. The task will automatically end and compile the results after 40 minutes.

Subject will be permitted to remove the sensors for the EOG and CO, as well as disconnect the sensors for the ECG and exit the pod, and then will be asked to perform a manipulation check questionnaire. The subject will be permitted to return to the gender-specific restroom to remove the ECG electrodes. A final debriefing will take place and the subject's test session will be concluded.

(6) Data Collection and Analysis: All performance data for the vigilance task will be recorded and output by software named Super Duper Lab. The data will

include the number of hits (correctly identifying a critical event), the number of misses (incorrectly identifying a critical event as a neutral one), and false alarms (incorrectly identifying a neutral event as a critical one).

The data from the physiological measures (ECG, EOG, CO) will also be analyzed to determine whether significant changes occurred during each experimental session and how these values correlated with changes in the performance data and temperature. First the physiology data collected during the first segment (20 minute period) of the vigilance task will be identified from each of the three devices. Any extraneous data or outliers will be identified and examined further to determine possible causes. The data will then be used to graph the physiology signals as a function of time and compared together with the performance data. Heart rate, heart rate variability, eye movements (e.g., rolling average of number of saccades, saccade duration, and voltage amplitude), eye blink rate, and cerebral blood flow can all be calculated for each individual and used to quantify a vigilance decrement. The physiology data from the second segment of the vigilance task will also be examined to draw qualitative conclusions about an individual's vigilance; however, the effects of fatigue and temperature will also have an effect on the signals.

To test whether localized temperature changes have an effect on vigilance performance one-way Analysis of Variance, with temperature as the independent variable and performance as the dependent variable will be conducted. An alpha of .05 will be used to discern whether different levels of the independent variable caused significant differences in performance. A Bonferroni correction will be used to investigate which of the three levels of temperature are significantly different from one another.

To test whether individual stress appraisals moderate the relationship between localized temperature changes and vigilance performance a hierarchical regression will be conducted. First, the dependent variable, performance, will be regressed on the two predictors, temperature change and stressor appraisal. Then the interaction term between the two predictors will be added. Change in R^2 will indicate how much variance the interaction term is adding and whether it is significantly different from zero.

Experiment 2 – Using physiology measures as real time feedback

If the results from the previous experiment show that vigilance performance does improve when localized temperature conditions change, then an additional experiment will be conducted. Experiment 2 will investigate whether performance can be additionally improved by using real-time physiological data to predict when vigilance is declining and implement a localized temperature change at that time.

Changes from the previous experiments include:
-Up to an additional 20 subjects
-New Item (5) – See below.
-Only one temperature condition (either a positive or negative) – Depending on the results from the previous experiments
-Temperature modified based upon a physiologically (from either ECG, EOG, and/or CO) determined change in vigilance for the experimental condition
-Additional analysis - Item (6)

(5) Test Sessions and Testing Sequence: After arrival, the subjects will receive an introduction to the research team and a briefing on the study and its goals. The informed consent document will be explained and the subjects will be allowed to read it thoroughly. Any questions they may have will be answered and the subjects will then be directed to sign giving their consent. Each subject will then be assessed for dominant hand by taking the Edinburgh Handedness Inventory (Appendix C). Normal visual acuity and depth perception are qualification prerequisites for this study. The researchers will be screening the subjects using two standard vision tests that only require minutes to administer, a 4 meter (13ft.) SLOAN Eye Chart (Precision Vision) and a TNO test for stereoscopic vision (Laméris Instrumenten b.v.). No medical diagnosis will be offered and subjects who fail any vision screening will only be excluded from participating. Then an in-depth description of the simulated air traffic control vigilance task will be read to them and examples of critical and neutral signals will be shown to them. Volunteer subjects will be randomly assigned to a positive, negative, or neutral (control) temperature condition and a description of the basic experimental setup will be provided.

The subjects will be fit with the ECG, EOG, and CO sensors and enter the pod, sitting on top of the thermoelectric pad. The thermoelectric blanket will be placed over the body of the subject, allowing free range of their hands. The subjects will then be given a clicker to hold in their dominant hand, which they will use to indicate when a critical signal is observed during the vigilance task. A computer screen, placed inside the pod, in front of the subject, will display a start up screen for the vigilance task telling subjects to press the clicker when they are ready to start the task. Before data collection begins, subjects will have 5 minutes to practice the vigilance task. Any subjects who detect less than 60% of the critical signals or make more than 5 false alarms during this portion of the study will be excluded from the rest of the study.

Upon successful completion of the practice period, the subjects will press the clicker to begin the 40 minute simulated air traffic control task. Software named Super Duper Lab will record the vigilance task results throughout the entire 40-minute session. Additionally, BIOPAC software will continue to record all of the ECG and EOG data and INVOS software for the CO data, but also monitor this data to determine when changes occur which signal a predetermined vigilance

decrement. The temperature changes, performance data, and physiology data will all be coupled within a single process to accurately keep the time scale consistent throughout the experiment. Depending on the condition assigned to each subject, after a vigilance decrement is determined from the physiology signal(s), the temperature of the pad and blanket will be either increased to 110°F/decreased to 65°F or remain the same temperature. If a subject is assigned to a temperature change condition, then the entire temperature change will occur within 1 minute of the switch being flipped on the thermoelectric pad and blanket. Physiology will continue to be recorded and used to determine vigilance decrements, at which time additional temperature changes will be triggered. The task will automatically end and compile the results after 40 minutes. Note that within this paradigm, the detection of an initial vigilance decrement will be used to trigger an increase or decrease in temperature from the baseline and any subsequent vigilance decrement detection will trigger the temperature to be returned to its initial value. The temperature will be cycled between these two conditions for subsequent vigilance decrement conditions. The software will limit changes in temperature such that no two temperature changes will be triggered within a time period of less than 5 minutes, preventing the rapid oscillation of temperature.

Subject will be permitted to remove the sensors for the EOG and CO, as well as disconnect the sensors for the ECG and exit the pod. The subject will be permitted to return to the gender-specific restroom to remove the ECG electrodes. A final debriefing will take place and the subject's test session will be concluded.

(6) Data Collection and Analysis: The physiology data will be analyzed as in Experiment 1, but with an additional real time component to ideally predict the vigilance decrement and counter it in real time. Performance data will be recorded and analyzed then compared to results from Experiment 1 to determine how the effects of temperature changes initiated from physiology signals differ from one at set time interval.

    e. <u>Safety monitoring</u>:

A medical consultant will be on-call during the testing.

    f. <u>Confidentiality protection</u>:

(1) Subjects will be listed by name on a contact roster and assigned a study number. The contact roster will be stored in a locked cabinet. The roster and test data will be kept separate. No other personal identifying information will be assigned to the data sets. The link to name and study number will be established so the subject can be contacted for testing and if a retest becomes necessary. Study staff will maintain direct control of data, paper records, and computer disks containing confidential information as they are transported within the

organization. Study staff will store personal identifiable records and signed Informed Consent Documents in locked file cabinets at RHCP and/or AFIT.

(2) At the completion of the protocol, all Informed Consent Documents are forwarded to the IRB and the link between the data and any personal identifiable information will be destroyed. Additionally all of the hard copy documents will be shredded.

(3) The data will be retained indefinitely for future research projects focusing on vigilance performance or analysis of physiology data.

10. Risk Analysis

All subjects participating in this study will be briefed on all aspects of the protocol and acknowledge their understanding and consent by signing the attached Informed Consent Document. Potential risks include discomfort from electrodes and sensors being placed on the chest and face as they might constrict the subject's movement; however, the only movement necessary during the study is holding and using a small hand-held clicker. If extreme movement is necessary, the electrodes and sensors will just pull off the adhesive pad connecting them to the skin and then have to be reattached.   Subjects could experience fatigue from performing the task. The subject can elect to stop a run at any time. Claustrophobia may be experienced from being enclosed in the pod. Subjects can open the cover and exit pod (as shown in Figure 1) at any time. Conservative limits have been set regarding the induced temperature changes. The thermoelectric pad and blanket temperature will be monitored during testing and immediately turned off if a temperature above 110°F or below 65°F is observed. Subjects will be given 5 minutes before the start of the task to sit in the pod so they can habituate both physically and psychologically to sitting in the pod. Subjects will be instructed to report immediately any unusual symptoms, such as dizziness, headache etc. Once again the subject can elect to stop a run at any time.

Users of testing equipment will be required to read and follow all operating procedures of the testing equipment prior to use. Contraindications, warnings, and cautions will be heeded by the investigators and test conductors.

An Air Force Research Laboratory Safety Permit was filled out by Keith Vossler and attached to this document, indicating that the equipment used in this study is of low risk to the subjects.

11. References

Aasman, J., Mulder, G., & Mulder, L. J. (1987). Operator effort and the measurement of heart-rate variability. Human Factors: The Journal of the Human Factors and Ergonomics Society, 29(2), 161-170.

Blascovich, J., & Tomaka, J. (1996). The biopsychosocial model of arousal regulation. In M. Zanna (Ed.), Advances in experimental social psychology (Vol. 28, pp. 1–51).

New York: Academic Press.

Bridges, Nathaniel Reese. Predicting Vigilance Performance Under Transcranial Direct Current Stimulation. M.S.Egr., Department of Industrial, Biomedical and Human Factors Engineering, Wright State University, 2011.

Bursill, A. E. The Restriction of Peripheral Vision During Exposure to Hot and Humid Condition. Quarterly Journal of Experimental Psychology, 10, 1958,113-129.

Davies, P., & Maconochie, I. (2009). The relationship between body temperature, heart rate and respiratory rate in children. Emergency Medicine Journal, 26(9), 641-643.

Faisal, A. A., Selen, L. P., & Wolpert, D. M. (2008). Noise in the nervous system. *Nature Reviews Neuroscience, 9* , 292-303.

Glaser, E. M., & Shephard, R. J. (1963). Simultaneous experimental acclimatization to heat and cold in man. The Journal of Physiology, 169(3), 592-602.

Hancock, P.A., & Hart, S.G. (2002). Defeating terrorism: What can human factors/ergonomics offer? *Ergonomics in design, 10,* 6-16.

Hebb, D. (1958). *A Textbook of Psychology.* Philadelphia : Saunders.

Helton, W. S., Hollander, T. D., Warm, J. S., Tripp, L. D., Parsons, K., Matthews, G., ... & Hancock, P. A. (2007). The abbreviated vigilance task and cerebral hemodynamics. Journal of Clinical and Experimental Neuropsychology, 29(5), 545-552.

Hitchcock, E. M. (2000). EFFECTS OF SIGNAL SALIENCE AND CUEING ON CEREBRAL BLOOD FLOW VELOCITY DURING SUSTAINED ATTENTION (Doctoral dissertation, University of Cincinnati).

Hitchcock, E. M., Warm, J. S., Matthews, G., Dember, W. N., Shear, P. K., Tripp, L. D., ... & Parasuraman, R. (2003). Automation cueing modulates cerebral blood flow and vigilance in a simulated air traffic control task. Theoretical Issues in Ergonomics Science, 4(1-2), 89-112.

Humphreys, M. S., & Revelle, W. (1984). Personality, motivation, and performance: a theory of the relationship between individual differences and information processing. *Psychological Review (91)* , 153-184.

Langhals, B., Burgoon, J. K., & Nunamaker Jr, J. F. (2011). Using Eye and Head Based Psychophysiological Cues to Enhance Screener Vigilance (Doctoral dissertation, University of Arizona).

Lazarus, R. S., & Folkman, S. (1984). Stress, appraisal, and coping. New York: Springer.

Lichstein, K. L., Riedel, B. W., & Richman, S. L. (2000). The Mackworth Clock Test: A Computerized Version . *The Journal of Psychology, 134(2)* , 153-161.

Mackworth, N. H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology*, *1* (1), 6-21.

Mackworth, N. H. (1950) *Researches on the Measurement of Human Performance.* Medical Research Council Special Report Series 268. London: His majesty's Stationary Office.

Matthews, G., & Davies, D. R. (1998). *Arousal and vigilance: The role of task demands.*, chap. 005, (pp. 113-144). Washington: American Psychological Association.

McIntire, L., Goodyear, C., Bridges, N., McKinley, R. A., Merritt, M., Griffin, K., & McIntire, J. (2011). Eye-Tracking: An Alternative Vigilance Detector. INFOSCITEX CORP DAYTON OH.

Pepler, R. D. The Effects of Climatic Factors on the Performance of Skilled Tasks by Young European Men Living in the Tropics. Report 156/53, March, 1953. Applied Psychology Research Unit, Royal Naval Personnel Research Committee, Great Britain.

Parasuraman, R. (1985). Sustained attention: A multifactorial approach. In M. I. Posner, & O. S. Marin (Eds.), *Attention and Performance XI* (pp. 493-511). New Jersey: Erlbaum Associates.

Parasuraman, R., & Davies, D. R. (1977). A taxonomic analysis of vigilance performance. In R. R. Mackie (Ed.), *Vigilance: Theory, operational performance, and physiological correlates* (pp. 559-574). New York: Plenum.

Parasuraman, R., Warm, J. S., & Dember, W. N. (1987). Vigilance: taxonomy and utility. In L. S. Mark, J. S. Warm, & R. L. Huston, *Ergonomics and human factors: Recent research* (pp. 11-32). New York, NY: Springer-Verlag.

Parasuraman, R., Warm, J. S., & See, J. E. (1998). Brain Systems of Vigilance. In R. Parasuraman, *The Attentive Brain* (pp. 221-256). Cambridge, MA: MIT Pres.

Poulton, E. C., Hitchings, N. B. and Brook, R. B. Effect of Cold and Rain Upon Vigilance of Lookouts. Ergonomics, 1965, 8, 163-168.

Prokopová, I. (2010). Noradrenaline and behavior. *Ceskoslovenská fysiologie 59(2)* , 51-58.

Rowe, D. W., Sibert, J., & Irwin, D. (1998, January). Heart rate variability: Indicator of user state as an aid to human-computer interaction. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 480-487). ACM Press/Addison-Wesley Publishing Co.

Sakai, L. M., Baker, L. A., & Dawson, M. E. (1992). Electrodermal lability: individual differences affecting perceptual speed and vigilance performance in 9 to 16 year-old children. *Psychophysiology (2)* , 207-217.

Satchel, M. (1993). *Cockpit monitoring and alerting systems*. Brookfield, VT: Ashgate.

Schneider, T.R. (2004). The role of neuroticism on psychological and physiological stress responses. Journal of Experimental Social Psychology, 40, 795-804.

Schneider, Tamera. (2008). Evaluations of stressful transactions: what's in an appraisal? Stress and Health 24: 151-158.

Sheridan, T. (1987). Supervisory control. In G. Salvendy (Ed.), *Handbook of human factors* (pp. 1243-1268). New York: Wiley.

Tomaka, J., Blascovich, J., Kelsey, R. M., & Leitten, C. L. (1993). Subjective, physiological and behavioral effects of threat and challenge appraisal. Journal of Personality and Social Psychology, 66, 248–260.

U.S. Food and Drug Administration. (2009, April 04). 510(k) Premarket Notification. Retrieved from http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpmn/pmn.cfm?ID=28667

Vallet, M. (2001). *Factors Influencing Driving Performance*. Kluwer Academic Publishers.

Vollrath, M., & Torgersen, S. (2000). Personality types and coping. Personality and Individual Differences, 29, 367–378.

Warm, J.S. (1977). Psychological processing in sustained attention. In R.R. Mackie (Ed.), *Vigilance: Theory, operational performance, and physiological correlates* (pp. 623-644). New York: Plenum.

Warm, J.S, Dember W. N., & Parasuraman, R. (1991) Effects of Olfactory Stimulation on Performance and Stress in a Visual Sustained Attention Task. J. Soc. Cosmet. Chem, 42, 199-210.

Warm, J. S., & Jerison, H. J. (1984). The Psychophysics of Vigilance. In J. S. Warm, *Sustained Attention in Human Performance* (pp. 15-59). New York, NY: John Wiley & Sons.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. Human Factors: The Journal of the Human Factors and Ergonomics Society, 50(3), 433-441.

Warm, J. S., Matthews, G., & Parasuraman, R. (2009). Cerebral hemodynamics and vigilance performance. Military psychology, 21, S75-S100.

Wolfe, D. E., & Noguchi, L. K. (2009). The use of music with young children to improve sustained attention during a vigilance task in the presence of auditory distractions. *J Music Ther, 46(1)* , 69-82.

Wright, K. P., Hull, J. T., & Czeisler, C. A. (2002). Relationship Between Alertness, Performance, and Body Temperature in Humans. American Physiological Society:283 (pp. 1370-1377)

12. Attachments
    a. Informed Consent Documents
    b. Curriculum Vitae of Investigators
    c. Edinburgh Handedness Inventory
    d. Stress Questionnaire
    e. Manipulation Check Questionnaire
    f. Air Force Research Laboratory Safety Permit
    g. BIOPAC Conformity Documentation
    h. Subject Recruiting Material
    i. FLIR T400 Technical Specifications

A. Informed Consent Documents

A.1 Experiment 1 Informed Consent

Informed Consent Document
For
Examining Localized Temperature Changes and Vigilance Performance
Experiment 1 – *Examining the effects of localized temperature changes on vigilance performance and stress appraisals + Understanding the relationship between ECG/EOG and vigilance performance*

RHC and AFIT, Building 33, Wright-Patterson AFB, OH

Principal Investigators: Michael E. Miller/Ph.D/Assistant Professor, AFIT/ENV,
                            (937) 255-3636 x4651, Michael.Miller@afit.edu

Associate Investigators: Justine D. Jeroski/Master's Student, AFIT/ENV,
                            Justine.Jeroski@afit.edu

                            Jessica S. Pack/Master's Student, 711HPW/RHCP,
                            Infoscitex, (937) 528-3615, Jessica.Pack.ctr@wpafb.af.mil

1. **Nature and purpose:** You have been offered the opportunity to participate in the "Examining Localized Temperature Changes and Vigilance Performance" research study. Your participation will occur in Room 023 of Building 33.

    The purpose of this research is to evaluate the effect of localized temperature changes on vigilance performance and whether individual stress appraisals moderate the relationship between localized temperature changes and vigilance performance. Heart rate, eye movements, eye blink rate, and brain blood flow data will be collected during the experiment to see how your body responds to changes in attention and temperature.

    The time requirement for each volunteer subject is anticipated to be a total of 1 visit of approximately 90 minutes each. A total of up to 54 subjects will be enrolled in this study.

2. **Experimental procedures:** If you decide to participate sensors will be fit to your chest and face to obtain heart rate, eye movement, and brain oxygenation data. These sensors will measure heart and eye muscle activation. To collect oxygenation data, a sensor will shine an infrared light onto your forehead and measure the light that is reflected. Calibration will take approximately 5-10 minutes during which time an electrocardiogram (ECG), an electrooculogram (EOG), and a cerebral oximeter will

begin collecting data. Prior to training, you will be asked to fill in a "handedness" questionnaire. You will then receive training on the 40-minute simulated air-traffic control vigilance task to familiarize yourself with the software and ask any questions. Following the training, you will be asked to fill out a ten-item stress appraisal scale. After the survey is complete, you will be asked to lie down in a pod on top of the thermoelectric pad (see figure 1). The thermoelectric blanket will be placed over your body, but will still allow free range of your hands. The pod's shield will be twisted closed to prevent you from becoming distracted by outside stimuli. You will be given a clicker to hold in your dominant hand which you will use to indicate when a critical signal is observed during the vigilance task. Examples of possible neutral and critical signals are shown in Figure 2.

Figure 1. The thermoelectric pad and blanket situated inside the pod while the shield is open and closed.

Critical Event (Collision Path)

Clockwise Flight Paths

Counter-clockwise Flight Paths

Neutral Event (Safe) Stimuli

Before the task starts, you will have 5 minutes to practice with the task to ensure you fully understand what you need to do. The simulated air traffic control vigilance task will then begin at the press of the clicker and proceed for 40 consecutive minutes. Physiology and performance data will be recorded throughout the test session. After 20 minutes, the thermoelectric material surrounding you may increase or decrease in temperature for the duration of the task. If a change is experienced, then the entire temperature change will occur within 1 minute of the switch being flipped on the thermoelectric pad and blanket. The task will automatically end and compile the results after 40 minutes. Following task completion, you will be permitted to remove the electrodes and sensors for the ECG, EOG, and CO devices, exit the pod, and then perform a manipulation check questionnaire.

3. **Discomfort and risks:**

   Potential risks include discomfort from electrodes and sensors being placed on your chest and face as they will constrict your movement; however, the only movement necessary during the study is holding and using a small hand-held clicker. If extreme movement is necessary, the electrodes and sensors will just pull off the adhesive pad connecting them to your skin and then have to be reattached.   You could experience fatigue from performin**g** the task or claustrophobia from being enclosed in the pod. You can choose to stop participating in the experiment, open the cover, and exit pod (as shown in Figure 1) at any time. Conservative limits have been set regarding the temperature changes, but you may feel warm or cool during the experiment. The thermoelectric pad and blanket temperature will be monitored during testing and immediately turned off if a temperature above 110°F or below 65°F is observed. You will be given 5 minutes before the start of the task to sit in the pod so they can get used to it. You should immediately report any unusual symptoms, such as dizziness, headache etc. Once again you can choose to stop at any time.

   The researchers using the testing equipment will be required to read and follow all operating procedures of the testing equipment prior to use. Any warnings and cautions will be addressed by the researchers.

4. **Precautions for female subjects or subjects who are or may become pregnant during the course of this study:** There are no special precautions for female participants.

5. **Benefits:** You are not expected to benefit directly from participation in this research study.

6. **Compensation:** If you are active duty military you will receive your normal active duty pay.

7. **Alternatives:** Your alternative is to choose not to participate in this study. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study should you wish to discontinue at any time before or at any time during the study.

8. **Entitlements and confidentiality:**

    a. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations and the Health Insurance Portability and Accountability Act (HIPAA), and its implementing regulations, when applicable, and the Freedom of Information Act, 5 U.S.C. Sec 552, and its implementing regulations when applicable. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored only on a secure server. It is intended that the only people having access to your personal information will be the researchers named above and the AFRL Wright Site IRB, the Air Force Surgeon General's Research Compliance office, the Director of Defense Research and Engineering office or any other IRB involved in the review and approval of this protocol. When no longer needed (after all data has been obtained) for research purposes the link between your personal identifiable information (e.g. name, contact information) will be destroyed and all hardcopies will be shredded. Non-identifiable data will be retained indefinitely for future research projects on vigilance performance or analysis of physiology data. Complete confidentiality cannot be promised, in particular for military personnel, whose health or fitness for duty information may be required to be reported to appropriate medical or command authorities. If such information is to be reported, you will be informed of what is being reported and the reason for the report.

    b. Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the 711 HPW/JA at DSN 986-5666. In the event of a research related injury, you may contact the medical monitor, TSgt Bethany Repp, of this research study at (937)-938-3702.

    c. The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. Participate only if you want to. Michael E. Miller or an associate has adequately answered any and all questions you have about this study, your participation, and the procedures involved. If you have any further questions, Michael E. Miller can

be reached at 255-3636 x4651. Michael E. Miller or an associate will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participate or may affect the risk involved, you will be informed. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study to discontinue. Additionally, the investigator or medical monitor of this study may terminate your participation in this study if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Kim London at (937) 656-5688 or kim.london@wpafb.af.mil.

d.   Personal Identifiable Information to be obtained for this study includes name, age, gender, and contact information.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature_____**Date**_____

Volunteer Name (printed) _____

Advising Investigator Signature _____ **Date** _____

Investigator Name (printed)_____

Witness Signature _____**Date** _____

Witness Name (printed)_____

We may wish to present some of the video/audio recordings from this study at scientific conventions or use photographs in journal publications. If you consent to the use of your image for publication or presentation in a scientific or academic setting, please sign below.

Volunteer Signature_____**Date**_____

Privacy Act Statement

94

Authority: We are requesting disclosure of personal information.. Researchers are authorized to collect personal information on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943.

Purpose: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate.

Routine Uses: Information may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care.

Disclosure: Disclosure of the requested information is voluntary.   No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

A.2 Experiment 2 Informed Consent
INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent Document
For
Examining Localized Temperature Changes and Vigilance Performance
Experiment 2 – Using physiology measures as real time feedback

RHC and AFIT, Building 33, Wright-Patterson AFB, OH

Principal Investigators: Michael E. Miller/Ph.D/Assistant Professor, AFIT/ENV,
                                  (937) 255-3636 x4651, Michael.Miller@afit.edu

Associate Investigators: Justine D. Jeroski/Master's Student, AFIT/ENV,
                                  Justine.Jeroski@afit.edu

                                  Jessica S. Pack/Master's Student, 711HPW/RHCP,
                                  Infoscitex, (937) 528-3615, Jessica.Pack.ctr@wpafb.af.mil

1. **Nature and purpose:** You have been offered the opportunity to participate in the "Examining Localized Temperature Changes and Vigilance Performance" research study. Your participation will occur in Room 023 of Building 33.

   The purpose of this research is to evaluate the effect of localized temperature changes on vigilance performance and whether individual stress appraisals moderate the relationship between localized temperature changes and vigilance performance. Heart rate, eye movements, eye blink rate, and brain blood flow data will be collected

during the experiment to see how your body responds to changes in attention and temperature.

The time requirement for each volunteer subject is anticipated to be a total of 1 visit of approximately 90 minutes each. A total of up to 20 subjects will be enrolled in this study.

2. **Experimental procedures:** If you decide to participate electrodes and sensors will be fitted to your chest and face to obtain heart rate, eye movement, and brain oxygenation data. Calibration will take approximately 5-10 minutes during which time an electrocardiogram (ECG), an electrooculogram (EOG), and a cerebral oximeter will begin collecting data. Prior to training, you will be asked to fill in a "handedness" questionnaire. You will then receive training on the 40-minute simulated air-traffic control vigilance task to familiarize yourself with the software and ask any questions. Following the training, you will be asked to lie down in a pod on top of the thermoelectric pad (See Figure 1). The thermoelectric blanket will be placed over your body, but will still allow free range of your hands. The pod's shield will be twisted closed to prevent you from becoming distracted by outside stimuli. You will be given a clicker to hold in your dominant hand which you will use to indicate when a critical signal is observed during the vigilance task. Examples of possible neutral and critical signals are shown in Figure 2.

Figure 1. The thermoelectric pad and blanket situated inside the pod while the shield is open and closed.

Critical Event (Collision Path)

Clockwise Flight Paths

Counter-clockwise Flight Paths

Neutral Event (Safe) Stimuli

Figure 2.   Possible critical event and neutral event displays from the simulated air traffic control vigilance task.

Before the task starts, you will have 5 minutes to practice with the task to ensure you fully understand what you need to do. The simulated air traffic control vigilance task will then begin at the press of the clicker and proceed for 40 consecutive minutes. Physiology and performance data will be recorded throughout the test session. Depending on the condition assigned to you, after a vigilance decrement is determined from the physiology signal(s), the temperature of the pad and blanket with either change or remain constant. If you are assigned to a temperature change condition, then the entire temperature change will occur within 1 minute of the switch being flipped on the thermoelectric pad and blanket. Physiology will continue to be recorded and used to determine vigilance decrements, at which time additional temperature changes will be triggered. The task will automatically end and compile the results after 40 minutes. Following task completion, you will be permitted to remove the electrodes and sensors for the ECG, EOG, and CO devices and exit the pod.

Discomfort and risks:
Potential risks include discomfort from electrodes and sensors being placed on your chest and face as they will constrict your movement; however, the only movement necessary during the study is holding and using a small hand-held clicker. If extreme movement is necessary, the electrodes and sensors will just pull off the adhesive pad connecting them to your skin and then have to be reattached.   You could experience fatigue from performing the task or claustrophobia from being enclosed in the pod.

You can choose to stop participating in the experiment, open the cover, and exit pod (as shown in Figure 1) at any time. Conservative limits have been set regarding the temperature changes, but you may feel warm or cool during the experiment. The thermoelectric pad and blanket temperature will be monitored during testing and immediately turned off if a temperature above 110°F or below 65°F is observed. You will be given 5 minutes before the start of the task to sit in the pod so they can get used to it. You should immediately report any unusual symptoms, such as dizziness, headache etc. Once again you can choose to stop at any time.

The researchers using the testing equipment will be required to read and follow all operating procedures of the testing equipment prior to use. Any warnings and cautions will be addressed by the researchers.

3. **Precautions for female subjects or subjects who are or may become pregnant during the course of this study:** There are no special precautions for female participants.

4. **Benefits:** You are not expected to benefit directly from participation in this research study.

5. **Compensation:** If you are active duty military you will receive your normal active duty pay.

6. **Alternatives:** Your alternative is to choose not to participate in this study. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study should you wish to discontinue at any time before or at any time during the study.

8. **Entitlements and confidentiality:**

   a. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations and the Health Insurance Portability and Accountability Act (HIPAA), and its implementing regulations, when applicable, and the Freedom of Information Act, 5 U.S.C. Sec 552, and its implementing regulations when applicable. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored only on a secure server. It is intended that the only people having access to your information will be the researchers named above and the AFRL Wright Site IRB, the Air Force Surgeon General's Research Compliance office, the Director of Defense Research and Engineering office or any other IRB involved in the review and approval of

this protocol. When no longer needed (after all data has been obtained) for research purposes the link between your personal identifiable information (e.g. name, contact information) will be destroyed and all hardcopies will be shredded. Non-identifiable data will be retained indefinitely for future research projects on vigilance performance or analysis of physiology data. Complete confidentiality cannot be promised, in particular for military personnel, whose health or fitness for duty information may be required to be reported to appropriate medical or command authorities. If such information is to be reported, you will be informed of what is being reported and the reason for the report.

b. Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the 711 HPW/JA at DSN 986-5666. In the event of a research related injury, you may contact the medical monitor, TSgt Bethany Repp, of this research study at (937)-938-3702.

c. The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. Participate only if you want to. Michael E. Miller or an associate has adequately answered any and all questions you have about this study, your participation, and the procedures involved. If you have any further questions, Michael E. Miller can be reached at 255-3636 x4651. Michael E. Miller or an associate will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participate or may affect the risk involved, you will be informed. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study to discontinue. Additionally, the investigator or medical monitor of this study may terminate your participation in this study if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Kim London at (937) 656-5688 or kim.london@wpafb.af.mil.

e.   Personal Identifiable Information to be obtained for this study includes name, age, gender, and contact information.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer
Signature_____**Date**_____

Volunteer Name (printed) _____

Advising Investigator Signature _____ **Date** _____

Investigator Name (printed)_____

Witness Signature _____**Date** _____

Witness Name (printed)_____

We may wish to present some of the video/audio recordings from this study at scientific conventions or use photographs in journal publications. If you consent to the use of your image for publication or presentation in a scientific or academic setting, please sign below.

Volunteer
Signature_____**Date**_____

Privacy Act Statement

B. Curriculum Vitae of Investigators

Principal Investigator:

Michael E. Miller, Ph.D
Assistant Professor Systems Integration

EDUCATION:

PhD, Industrial and Systems Engineering, Virginia Polytechnic Institute and State University
MS, Industrial and Systems Engineering, Ohio University, Athens, OH, November 1989
BS, Industrial and Systems Engineering, Ohio University, Athens, OH, June 1987

RELEVANT EXPERIENCE:

Assistant Professor, Systems Integration, AFIT, WPAFB, OH, July 2010 to Present

Senior Research Scientist, Eastman Kodak Company, Rochester, NY, Sept 1995 to April 2010
   Led and applied image science and systems engineering to research and develop novel OLED system architectures for displays and lighting
   Developed and led a group of engineers and psychologists to study and apply human vision principles to enhance and quantify image quality
   Designed and evaluated the human-machine interface for digital cameras

PUBLICATIONS/PRESENTATIONS:

Peer Reviewed Journal Publications:

1. Parr, J.C., Miller, M.E., Pellettiere, J.A., and Erich, R.A. (in press). Neck Injury Criteria Formulation and Injury Risk Curves for the Ejection Environment: A Pilot Study, Aviation, Space and Environmental Medicine Journal.

2. Ochs, K.S.; Miller, M.E.; Thal, A.E.; and Ritschel, J.D. (in press). A proposed method for analyzing infrastructure investment decisions involving rapidly evolving technology: A case study in LED streetlights, Journal of Management in Engineering. Available on DOI Website: http://ascelibrary.org/doi/abs/10.1061/(ASCE)ME.1943-5479.0000177.Gilman, J.M.; Miller, M.E.; Grimaila, M.R. (in press) A simplified control system for a daylight-matched LED lamp, Lighting Research and Applications.

3. Colombi, J.; Miller, M.E.; Schneider M.; McGrogan, J.; Long, D.S.; and Plaga, J. (2012). Predictive Mental Workload Modeling for Semi-Autonomous System Design: Implications for Systems of Systems, Journal of Systems Engineering, 15(4).

4. Miller, M.E. and Murdoch, M.J. (2009). RGB to RGBW conversion with current limiting for OLED displays, Journal of the Society for Information Display, 17(3), pp. 195-202.

5. Spindler, J.P., Hatwar, T.K., Miller, M.E., Arnold, A.D., Murdoch, M.J., Kane, P.J., Ludwicki, J.E., Alessi, P.J. and Van Slyke, S.A., (2006). System considerations for RGB OLED displays, Journal of the Society for Information Display, 14(1), pp. 37-48.

6. Arnold, A., Castro, P., Hatwar, T., Hettel, M., Kane, P., Ludwicki, J., Miller, M., Murdoch, M., Spindler, J., Van Slyke, S., Mameno, K., Nishikawa, R., Omura, T.,

and Matsumoto, S., (2005). Full-color AMOLED with RGBW Pixel Pattern, Journal of the Society for Information Display, 13(6), pp. 525-535.

7. Miller, Michael E. and Yang J. (2003). Visual display characterization using temporally modulated patterns, Journal of the Society for Information Display, 11(1), pp. 183-190.

8. Yu, Qing, Luo, Jiebo and Miller, Michael E. (2002). A Triage Metric of Determining the Extent of DCT-Based Compression Artifacts in a Digital Image, Journal of Imaging Science and Technology, 46 (5), pp. 443-452.

9. Zwahlen, H. T., Miller, M. E., and Yu, J. (1989). Effects of misaimed low beams and high beams on the visual detection of reflectorized targets at night. Transportation Research Record, 1247, 1-11.

10. Zwahlen, H. T., Miller, M. E., Khan, M., and Dunn, R. (1988). Optimization of post delineator placement from a visibility point of view. Transportation Research Record, 1172, 78-87.

Select Conference Papers (last 5 years):

1. Uribe, D., Miller, M.E., and Smith, S. (2013). An analysis of the vestibulo-ocular reflex during vibration, Proceedings of the International Symposium on Aviation Psychology, Dayton, OH, Vol. 4, pp. 506-511.
2. Santana, L.C.R.A., Langhals, B.T., Miller, M.E. and Finomore, V. (2013) Does supplementary computer generated cueing enhance controller efficiency in a congested communication environment?, Proceedings of the International Symposium on Aviation Psychology, Dayton, OH, Vol. 4, pp.226-231.
3. Russi, J.G., Langhals, B.T., Miller, M.E., Heft, E. (2013). The effects of stereoscopic radar displays on air traffic controller performance, Proceedings of the International Symposium on Aviation Psychology, Dayton, OH, Vol. 4, pp. 317-322.
4. 4. Parr, J.C., Miller, M.E., Bridges, N.R., Buhrman, C.E. Perry, N.L. Wright (2012). Evaluation of the Nij Neck Injury Criteria with Human Response Data for Use in Future Research on Helmet Mounted Display Mass Properties, Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting. Boston, MA.
5. Gilman, J. and Miller, M.E. (2012). Daylight Matching with Blended-CCT LED Lamp, Proceedings of the Society for Information Display, Boston, MA.
6. Ochs, K.S., Miller, M.E., and Thal, A. (2012). Time Valued Technology: Evaluating Infrastructure Replacement with Rapidly Emerging Technology, Proceedings of the Industrial and Systems Engineering Research Conference, Orlando, FL.
7. Machuca, J., Miller, M.E., and Colombi, J. (2012). A Cognitive Task Analysis-based Evaluation of Remotely Piloted Aircraft Situation Awareness Transfer Mechanisms, IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, New Orleans, LA.

8. Pond, T., Webster, B., Machuca, J., Colombi, J. Miller, M. and Gibb, R. (2012). Allocation of Communications to Reduce Mental Workload, Conference on Systems Engineering Research, St. Louis, MO.

9. Miller, M.E. and Gilman, J. (2011). Daylight-Matched Lighting for Mixed Illumination Environments, Illuminating Engineering Society Conference, Austin, TX.

10. Schneider, M., McGrogan, J., Colombi, J., Miller, M. and Long D. (2011). Modeling Pilot Workload for Multi-Aircraft Control of an Unmanned Aircraft System, INCOSE International Workshop, Denver, CO.

11. McGrogan, J., Schneider, M., Wirthlin, R., Colombi, J. and Miller, M. (2011). Using Discrete Event Simulation for Manpower Estimates of Semiautonomous Systems, Proceedings of the Conference on Systems Engineering Research, Redondo Beach.

12. McGrogan, J., Schneider, M., Wirthlin, R., Colombi, J., and Miller, M. (2011). Predicting the Impact of Multi-Aircraft Control on UAS Operations, Industrial Engineering Research Conference, Reno, NV.

13. Miller, M.E. and Basile, J.M. (2010). Luminance and Saturation Control for RGBW OLED Displays. In Proceedings of the Society for Information Display, Seattle, WA, vol., 41, pp. 269-272.

14. Miller, M.E., Hamer, J.W., Ludwicki, J.E. and Arnold A.D. (2009). Exploiting the Flexibility of RGBW OLED Displays: Trading Color Saturation for Power. In Proceedings of the Society for Information Display, San Antonio, TX: Society for Information Display, vol., 40, pp. 935-938.

15. Miller, M.E., Alessi, P.J., Ludwicki, J.E., White, C.J. and Basile, J.M. (2009). Perceptual Effects of Reducing Blue Power. In Proceedings of the Society for Information Display, San Antonio, TX: Society for Information Display, vol., 40, pp. 1010-1013.

Associate Investigator:

<div align="center">

Justine D. Jeroski
Master's Student

</div>

EDUCATION:

Bachelor of Science, Biomedical Engineering, Graduated May 2011
Case Western Reserve University, Cleveland, OH

Master of Science, **Systems Engineering**, Projected graduation March 2014
Air Force Institute of Technology (AFIT), WPAFB, OH

PROFESSIONAL TRAINING/COURSEWORK:

HFEN 610 Human Performance Measurement
> Course focused on theories, concepts, and methods for measuring and evaluating human performance. Influence of fatigue, environmental/task stressors and social/team factors were discussed.

HFEN 663 Human Interaction Technologies
> Course goal was to understand and improve the physical linkages between a human user and a system. The physical capabilities and limitations of the human perceptual system, the natural modes of interaction, and methods for specifying input/output device technology were considered.

HFEN 560 Human Factors Engineering
> Course focused on knowledge on human capabilities and limitations useful in the design of the human interface, getting acquainted with recent research and presentation methods within the field of human factors, and understanding the tradeoffs in the design of the human interface.

RELEVANT EXPERIENCE:
Worked as a crew station engineer in the Air Force Life Cycle Management Center (AFLCMC) in the Crew Systems Branch, WPAFB, OH. Duties: analysis of pilot and crew accommodation designs and airworthiness considerations. November 2011 to present.

PROFESSIONAL SOCIETIES: AFIT's Sigma Beta Chapter of Sigma Iota Epsilon (SIE)

Associate Investigator:

Jessica S. Pack
Master's Student

EDUCATION:

Bachelor of Science, Biology, Graduated May 2011
Indiana University, Bloomington, Indiana

Master of Science, **Human Factors Psychology**, Projected graduation May 2014
Wright State University, Fairborn, OH

PROFESSIONAL TRAINING/COURSEWORK:

PSY 7010 & 7020 Research Design and Quantitative Methods I & II

Course goal was to understand the foundation of experimental design and apply quantitative techniques to experimental and field research. Complex analyses of variance, multiple regression, and non-parametric techniques were covered in the course. Computation and computer skills were mastered.

PSY 8640 Research Methods in Industrial/Organizational Psychology
The course focused on the unique methodological challenges faced by I/O researchers. Theory, causation, and experimental validity were reviewed. Various research designs (e.g., experiments, quasi-experiments, correlation and regression analysis, ethnographic study) were discussed. Methods of data collection (e.g., unobtrusive measurement, survey, qualitative) were reviewed.

RELEVANT EXPERIENCE:

Research Scientist, Infoscitex, WPAFB, OH, June 2011 to Present
Developed protocol and testing procedures for several thermoelectric prototypes (sleeping cot, patient litter, vest, and sleeping bag) that will provide personal heating and cooling to troops along with immediate heat stress treatment.
Assisted with data and temperature collection during non- subject and subject testing of several thermoelectric prototypes, leading to the establishment of heating and cooling parameters.
Analyzed and transformed temperature data using statistical software packages such as Microsoft Excel and IBM SPSS.
Wrote technical reports, proposals, and test plans describing and showcasing the capabilities of thermoelectric technology using Microsoft Word.
Assisted with data collection and organization for the Helmet Mounted Pulse Oximeter now being used by F-22 pilots.

PUBLICATIONS:

1. Pack, J., Fox, J., Moussa, M., Tripp, L. (2012). Thermoelectric Patient Litter and Blanket Heating and Cooling Evaluation. AFRL RHCPT Technical Report. (In Press).
2. Steinhauer, B., Pack, J., Perry, C., Smith, S., Tripp, L., Heitzman, J. (2012) Assessment of a Thermoelectric Vest Through Physical and Mental Performance. AFRL RHCPT Technical Report. (In Press).
3. Pack, J., Dao, T., Steinhauer, B., Tripp, L., Perry, C. (2011). Thermoelectric Technologies for the Use of Heating and Cooling. AFRL RHCPT Technical Report. (In Press).

C. Edinburgh Handedness Inventory
http://zhanglab.wdfiles.com/local--files/survey/handedness.html

This handedness survey is based on Edinburgh Handedness Inventory.
Please indicate which hand you prefer for each of the following activities.

Task	Preference	Left	Right
1. Writing	<Choose one> ▼		
2. Drawing	<Choose one> ▼		
3. Throwing	<Choose one> ▼		
4. Using scissors	<Choose one> ▼		
5. Brushing teeth	<Choose one> ▼		
6. Using a knife (without a fork)	<Choose one> ▼		
7. Using a spoon	<Choose one> ▼		
8. Using a broom (dominant hand)	<Choose one> ▼		
9. Striking a match	<Choose one> ▼		
10. Opening a jar	<Choose one> ▼		
Total		**0**	**0**

Your Handedness Score
Unknown
(Finish the ten items to see your score.)

-1.0	<--	**-0.5**	<--	**0.0**	-->	**+0.5**	-->	**+1.0**
Pure left hander		Mixed left hander		Neutral		Mixed right hander		Pure right hander

Your handedness score is calculated using this formula: (Right - Left) / (Right + Left).

D. Stress Questionnaire

A. How threatening do you expect the upcoming task to be?

Not Threatening						Threatening
1	2	3	4	5	6	7

B. How demanding do you think the upcoming task will be?

Not Demanding						Demanding
1	2	3	4	5	6	7

C. How stressful do you expect the upcoming task to be?

Not Stressful						Stressful
1	2	3	4	5	6	7

D. To what extent do you think you will need to exert yourself to deal with this task?

Not at all						A lot
1	2	3	4	5	6	7

E. How much effort (mental or physical) do you think the situation will require you to expend?

None						A lot
1	2	3	4	5	6	7

F. How important is this task for you?

Not Important						Important
1	2	3	4	5	6	7

G. How uncertain are you about what will happen during this task?

None						A lot
1	2	3	4	5	6	7

H. How committed are you to doing this task well?

Not Committed						Committed
1	2	3	4	5	6	7

I. How well do you think you can manage the demands imposed on you by this task?

Not well at all						Well
1	2	3	4	5	6	7

J. How able are you to cope with this task?

Not Able						Able
1	2	3	4	5	6	7

K. How well do you think you will perform this task?

Not well at all						Well
1	2	3	4	5	6	7

Directions: Using the following scale, indicate to what extent you feel this way right now, that is, at the present moment.

1	2	3	4	5
Slightly or not at all	A little	Moderately	Quite a bit	Extremely

1. _____ Interested   6. _____ Distressed

2. _____ Excited   7. _____ Upset

3. _____ Enthusiastic   8. _____ Irritable

4. _____ Alert   9. _____ Nervous

5. _____ Determined   10._____ Jittery

E. Manipulation Check Questionnaire

1. Did you notice a temperature change?

   Yes   No

2. How would you rate the temperature of the pad/blanket at the beginning of task?
   Cold   1   2   3   4   5   Hot

3. How would you rate the temperature of the pad/blanket at the end of task?
   Cold   1   2   3   4   5   Hot

4. How annoyed did you feel over the course of the task?
   Not Annoyed   1   2   3   4   5 Annoyed

5. How would you rate your comfort over the course of the task?
   Comfortable   1   2   3   4   5 Uncomfortable

F. Air Force Research Laboratory Safety Permit

Air Force Research Laboratory Safety Permit			

Permit Number	Permit Expiration	Activity OPR	Office Symbol AFRL/ RHC
2013-33 RHC	05 / 31 / 2015	Name: Jessica Pack	Phone DSN:798-3615 Comm: 937-938-3615

1. Activity Location Building 33, Room 023	2. Job Order Number
3. Activity Title	4. Expected Activity Duration
Vigilance Performance Research Using Pod	FROM 05 / 31 / 2013 TO 05 / 31 / 2015

5. Emergency Contacts	Office Symbol	Office Phone		After-Hours Contact
Name: Lloyd D, Tripp	AFRL/ RHC	DSN: 785-8887	Comm: 937-255-8887	Bldg Front Door Phone Numbers
Name: Jessica Pack	AFRL/ RHC	DSN: 798-3615	Comm: 937-938-3615	Bldg Front Door Phone Numbers
Name:	AFRL/	DSN:	Comm:	

6. Activity Description *(Expand on attachments, as needed)*

The pod ensures that research participants are not distracted during testing. For this particular upcoming study, volunteers will sit in the pod and perform a cognitive task called SuperDuper Lab. Two computers will be used to run the task and a heating/cooling pad will be used to determine if temperature changes increase/decrease vigilance performance.

*1 MetroNaps Energy Pod, maximum draw: 5 amp, power consumption: 5 watts, internal voltage: 12 volts dc, hood rotates.
*2 Omega Complete Wireless Thermocuple Connector System, UWTC-1, ISM 2,4 GHz,direct sequence spread spectrum, (2.450 to 2.490GHz - 12 channels, RF Link Range of up to 65 in indoor.
*3 Tempronics Thermoelectric Pad, 55 to 110 deg F. Designed for this purpose.

7. Hazard Evaluation *(Hazard Evaluation Guidelines are available from the System Safety Manager (SSM))*

A. HAZARD	B.	C. QUANTITY/POWER/LOCATION/OTHER DESCRIPTIVE INFORMATION	D. COMPLETED BY SSM Risk Level
a. IONIZING RADIATION	☐		
b. RF RADIATION	☑	*2	IV D 19 Low
c. LASERS	☐		
d. TOXIC MATERIALS	☐		
e. NOISE	☐		
f. ENERGY STORAGE	☐		
g. MECHANICAL MOTION	☑	*1	IV D 19 Low
h. EXPLOSIVES	☐		
i. FLAMMABLES	☐		
j. HIGH VOLTAGE ELECTRICAL	☐		
k. CHEMICAL REACTION	☐		
l. WATER REACTIVE	☐		
m. HIGH TEMPERATURE	☑	*3	IV D 19 Low
n. CRYOGENICS	☐		
o. HIGH PRESSURE	☐		
p. HIGH VACUUM	☐		
q. UNATTENDED EQUIPMENT	☐		
r. FUEL HANDLING	☐		
s. COMPUTER CONTROL	☑	Control of vigilance task display (2 units) and laptop *2 See Section 11.	IV D 19 Low
t. OTHER	☐		
u. OTHER	☐		

See AFI 91-202 AFRL Supplement to determine Test Approval Authority.		E. Overall Risk Level: **Low**

System Safety Manager: Office Symbol: AFRL Det 1/SE	Name Keith Vossler	Signature VOSSLER.KEITH.A.12 30263716	Date May 31, 2013
Facility Approval: Office Symbol: N/A	Name Jessica Pack	Signature PACK.JESSICA.SPEN CER.1407678008	Date Jun 3, 2013
Test Approval Authority: Division	Name & Office Symbol Lloyd D, Tripp, RHC	Signature TRIPP.LLOYD.D.JR.10 97210825	Date June 12, 2013

AFRL FORM 5, Jan. 08   Page 1 of 2   PREVIOUS EDITIONS OBSOLETE
Prescribing Directive: AFRL Sup 1/AFI 91-202

Air Force Research Laboratory Safety Permit

Staff Coordination (if required)

Position Title	Name & Office Symbol	Signature		Date	
Position Title	Name & Office Symbol	Signature		Date	

8. Test/Facility (List all the interfaces to the equipment or facility, of power, fluids, type test etc.)

MATERIAL FLUID ETC	VOLTAGE PRESSURE ETC	FREQUENCY TEMPERATURE ETC	SOURCE	QUANTITY OR FLOW	REMARKS

9. Safety Critical Components/Procedures

1. Fire extinguisher located in hallway by elevator.
2. Ensure all tools associated with experiments/testing/operation/maintenance are accounted for prior to initiating system/item testing/use.

10. Personal Protective Equipment Record (Specify)

☐	a. HEAD	Type:	☐	e. RESTRAINTS	Type:
☐	b. HEARING	Type:	☐	f. GLOVES AND APRONS	Type:
☐	c. FACE AND EYE	Type:	☐	g. SHOES	Type:
☐	d. RESPIRATORY	Type:	☐	h. OTHER	Type:

11. The following may be used as a continuation of other blocks for additional coordination, recording job training, licenses, etc.

7.A.s.C (Continued): Display computers plugged into power isolation systems.

INSTRUCTIONS FOR COMPLETING AFRL FORM 5

Block	SSM Action	Activity Mgr Action	Explanation
Permit Number	X		Permit Number: Assigned by SSM
Permit Expiration	X		Permit Expiration: Based upon Overall Risk Level determined in Block 7E: High (6 months), Medium (1 year), Low (2 years)
1		X	Self-explanatory
2		X	Self-explanatory
3		X	Self-explanatory
4		X	Self-explanatory
5		X	Only use government on/off-duty phone numbers
6		X	Provide a brief description of activity purpose, objectives, function, capabilities and relation to facility (if applicable)
7B		X	Indicate hazard presence with an X
7C		X	Provide relevant information for hazard evaluation
7D	X		Using the Risk Assessment Matrix and criteria from Attachment 7, assign appropriate risk level (Low, Medium, High) based on hazard probability and severity
7E	X		Assign Overall Risk Level based upon highest individual hazard risk levels AFTER all mitigation procedures are in place
Facility Approval	X		If the approval authority does not own the facility, the SSM requires an additional facility authorization. TAA and facility approvals will be at the same management level.
Test Approval Authority	X		Test Approval Authority: Drop down menu selection based on guidelines set in AFI 91-202 AFRL Supplement for Low, Medium, or High activities
Staff Coordination		X	Staff Coordination: As required, include appropriate levels of coordination up to Test Approval Authority
8		X	List applicable interfaces to equipment or facility
9		X	Identify/describe single point failures that could cause an accident
10	X	X	Indicate required Personal Protective Equipment with an X. Describe type in adjacent box
11	X		Use this block for continuation from other blocks and/or additional pertinent information, as needed

G. BIOPAC Conformity Documentation

EC Declaration of Conformity

Classification

The MP150 System from BIOPAC Systems, Inc. is designed for use in life science research investigations. The MP150 System is a user-customized, physiological signal recording instrument. The MP150 System is intended for physiological research purposes and is designed to satisfy certain applicable test standards.

BIOPAC Systems, Inc. does not condone the use of its instruments for clinical medical applications. Instruments, components and accessories provided by BIOPAC Systems, Inc. are not intended for the diagnosis, mitigation, treatment, or prevention of disease.

Conformity

According to the original Low Voltage Directive 73/23/EEC and subsequent amendments which presently constitute Low Voltage Directive 2006/95/EC, the MP150 System conforms with the following standards as far as applicable:

   EN 60950-1

According to the Electromagnetic Compatibility Directive 89/336/EEC and later replaced by EMC Directive 2004/108/EC, the MP150 System conforms with the following standards as far as applicable:

   Emissions: EN 55011
   Immunity: EN 61000-4-2, EN 61000-4-3

Submitted June 17, 2011

Alan J. Macy
Research and Development Director
BIOPAC Systems, Inc.

Self-Declaration of Conformity

Classification

The MP150 System from BIOPAC Systems, Inc. is designed for use in life science research investigations. BIOPAC Systems, Inc. does not condone the use of its instruments for clinical medical applications. Instruments, components and accessories provided by BIOPAC Systems, Inc. are not intended for the diagnosis, mitigation, treatment or prevention of disease.
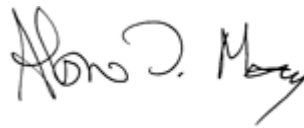
The MP150 System is a user-customized, physiological signal recording instrument. The MP150 System is intended for physiological research purposes and is designed to satisfy certain applicable medical safety requirements.

The MP150 System is not, solely, designed for use in clinical medical applications. Individuals or businesses that employ the MP150 system, as a sub-assembly for these purposes, are subject to the local relevant standards for their complete system offering.

With respect to the criteria established by COUNCIL DIRECTIVE 93/42/EEC of June 14, 1993, the MP150 System is not considered a medical device. Accordingly, the MP150 System is subject to the Low Voltage (2006/95/EC) and Electromagnetic Compatibility (2004/108/EC) Directives.

However, the MP150 System can be used to collect physiological data from human subjects for educational and research purposes. Accordingly, BIOPAC Systems, Inc. has tested the MP150
System to certain applicable medical device standards, even though, strictly considered, the MP150 is not a medical device. The applicable standards for medical safety requirements are determined by IEC 60601-1 and the applicable standards for electromagnetic compatibility requirements are determined by IEC 60601-1-2.

BIOPAC Systems, Inc. has attempted to reconcile the classification and testing requirements for the MP150 System by performing a series of relevant tests. These test standards and methods have been guided by addressing the applicable parts of IEC 60601-1 and IEC60601-1-2.

The MP150 System and Accessories product line from BIOPAC Systems, Inc., as specified in the Research catalog, conform to the following standards as far as applicable:

Electromagnetic Compatibility Test Standards

Emissions
Conducted Emissions:	EN 55011
Radiated Emissions:	EN 55011

Immunity
Electrostatic Discharge:	EN 61000-4-2
Radiated RF:	EN 61000-4-3

Medical Safety Test Standards
Earth Leakage Currents:	IEC 60601-1
Patient Leakage Currents:	IEC 60601-1
Insulations:	IEC 60601-1
Dielectric Strengths:	IEC 60601-1

Creepages and Air Clearances: IEC 60601-1

Electromagnetic Compatibility Testing Considerations
The MP150 System is designed to be used in physiological research and teaching laboratories and accordingly is formally subject to EN 55011 Electromagnetic Compatibility Test Standards.

Electromagnetic Compatibility Testing Configuration
The MP150 System was connected to a standard PC compatible computer, with all I/O ports properly terminated. The MP150 was initialized for standard operation prior to performing measurements.

Conducted Emissions
The MP150 System met the level imposed by the average conducted emissions limit through the use of a quasi-peak detector, accordingly the MP150 System was deemed to meet both quasi- peak and average conducted emission limits. The data set was reduced to indicate worst case expected readings. The highest conducted emission values for a particular frequency, in any frequency band, were plotted (see Appendix) as representative of the entire band.

Radiated Emissions
The MP150 System met the level imposed by the quasi-peak limit through the use of a quasi-peak detector. The readings at any particular frequency were observed for a 15 second period. The highest stable reading during this time period was recorded.

The data set was reduced to indicate worst case expected readings. The highest radiated emission values for a particular frequency, in any frequency band, were plotted (see Appendix) as representative of the entire band.

Immunity Testing
When exposed to Air (8 kV) and Contact (6 kV) Discharge, the MP150 System continued to operate in a normal fashion. When exposed to Radiated RF of 3 V/m (80 MHz to 2.5 GHz), the MP150 System continued to operate in a normal fashion.

Medical Safety Testing Considerations
The MP150 System is a user-customized, physiological signal recording instrument. The MP150 System is intended for physiological research purposes and is designed to satisfy certain applicable medical safety requirements.

The MP150 System is not, by itself, designed for use in clinical medical applications. Individuals or businesses who employ the MP150 system, as a sub-assembly, for these purposes are subject to the local relevant standards for the complete clinical system offering.

For the relevant medical safety tests, the MP150 System was evaluated in accordance to the applicable standards associated with IEC60601-1.

Medical Safety Testing Configuration
The MP150 System was connected to a standard PC compatible computer, with all I/O ports properly terminated. The MP150 System was initialized for standard operation prior to performing measurements.

Leakage Current Testing
For the MP150 system, the applicable measurements concern Earth Leakage currents, Enclosure Leakage current and Patient Leakage currents. See the Appendix for test procedures.

IEC60601-1 Earth Leakage Current limits
    500µA (Normal) and 1000µA (Single Fault Condition)

        In Normal Conditions, the MP150 leakage current is: < 8 µA
        In S.F.C. Conditions, the MP150 leakage current is: < 200 µA

IEC60601-1 Enclosure Leakage Current limits
    100µA (Normal) and 500µA (Single Fault Condition)

        In Normal Conditions, the MP150 leakage current is: < 8 µA
        In S.F.C. Conditions, the MP150 leakage current is: < 200 µA

IEC60601-1 Patient Leakage Current limits (Floating Applied part to Earth)
    100µA (Normal) and 500µA (Single Fault Condition)

        In Normal Conditions, the MP150 leakage current is: < 8 µA
        In S.F.C. Conditions, the MP150 leakage current is: < 200 µA

IEC60601-1 Patient Leakage Current limits (Mains Voltage on the Floating Applied part)
    5000µA (Single Fault Condition) – 240 VAC + 10% @ 60 Hz

        In S.F.C. Conditions, the MP150 leakage current is:
                        < 100µA   120 VAC + 10% @ 60 Hz
                        < 200µA   240 VAC + 10% @ 60 Hz

Dielectric Strength Testing
In reference to the MP150 System, the following definitions apply:

Mains or Live part: Subject to Wall Transformer (adapter)
Signal Input/Output part: Subject to Serial (USB) Computer Connection
Floating Applied part: Subject to Analog/Digital Connections

At least Double or Reinforced Insulation is required between the Mains (Live) part and Floating Applied part. This insulation was tested at 4000 V. No flashover or breakdown was observed.

At least Basic Insulation is required between a Floating Applied part and Signal Input/Output part. The Basic Insulated portions (DC/DC converters, optocouplers, and Ethernet transformer) of the MP150 System were tested to 1500 V. No flashover or breakdown was observed.

Creepage Distance and Air Clearance Testing
At least Basic Insulation is required between a Floating Applied part and a Signal Input/Output part. The MP150 unit has internal Creepage Distance and Air Clearance spacing designed to meet Basic or Supplementary Insulation requirements. These requirements are:

Basic Insulation
        Creepage Distance   3.0 mm
        Air Clearance   1.6 mm

 Double or Supplementary Insulation
        Creepage Distance   4.0 mm
        Air Clearance   2.5 mm

MP150 Internal Construction (Spacing between Floating Applied part and Signal Input/Output part)
        Creepage Distance   4.0 mm

Air Clearance   3.0 mm

Technical Documentation

Introduction

A representative sample of the MP150 System was examined and is described in the body of this report. Unless specifically stated otherwise, the following general definitions, terminology, and construction details apply:

Agency Approvals:
An asterisk (*) denotes that the agency logo appears on the
component. C or CSA = CSA Certified   UL = UL Listed
UR = UL Recognized   CUL = UL Listed to Canadian Standards

SELV:
All references to "SELV" denote Safety Extra-Low Voltage (less than 25 VAC or 60 VDC) non- hazardous secondary circuits.

Metal:
All references to "metal" denote painted or plated steel (minimum No 20 MSG) or aluminum (minimum No 16 AWG).

Dimensions:
(Dim) All dimensions specified are approximations only.

Internal Wiring:
All primary, secondary and grounding circuit conductors are certified, Type TEW, TR-64, TR-32, AWG SR-PVC or AWM XL-PVC, rated minimum 80°C, 300 VAC. All wiring is suitably routed and secured away from sharp edges and moving parts to prevent chafing of the insulation. Alternatively, additional insulation is provided where the wiring passes over sharp edges and through holes.

SELV Wiring:
All non-certified conductors and connectors in SELV secondary circuits have insulation materials with a flammability rating of 94V-1 or better.

Sleeving:
All thermoplastic and other insulating tubing used in primary and secondary circuits are certified, rated minimum 105°C, 300 VAC; or Teflon, rated minimum 200°C, 300 VAC.

Crimp Connectors:
All crimp-type connectors used in primary, secondary and grounding circuits are certified and appropriately sized for the gauge of conductors used, vinyl insulated (optional for grounding), rated minimum 90°C, 250 VAC.

Connectors:
All connectors used in primary and secondary circuits are certified, appropriately sized for the number and gauge of conductors used, rated minimum 250 VAC.

Printed Wiring Boards (PWB):
All PWBs are made of paper phenolic, paper epoxy or glass epoxy, minimum 1.6 mm thick, flammability rated 94V-1 or better.

<u>Spacings</u>:
All spacings in primary, secondary, and subject circuits between PWB conductive traces, and between other bare live parts and ground, conform to conform to Table XVI of IEC 60601-1.

<u>Bonding</u>:
All accessible metal parts liable to become energized are acceptably connected together, and to the grounding means, by straps and/or conductors, bolts, screws, and washers (to ensure surface coating penetration), in conformance to Clause 3.4 of CSA Standard C22.2 No 0.4.

System Description

<u>General</u>:
The MP150 System is a stackable, modular system intended for the monitoring, recording, and analyzing of physiological data in the life science research environment. The system is not intended for clinical medical applications and is not for the diagnosis, mitigation, treatment or prevention of disease.

The MP150 System is a data acquisition hardware platform upon which various life science research and development systems can be implemented. The MP150 unit is an electrical system which contains high isolation DC-DC converters, optical isolators, amplifiers, analog to digital converters, microprocessor, and support components.

The MP150 unit resides in a durable ABS plastic (UL type 94HB) enclosure and connects to the computer (either PC compatible or Macintosh) via an Ethernet or serial (USB) extension cable. Modules for measuring a variety of physiological signals are plugged into the MP150 unit. Up to
16 modules can be used simultaneously with a single MP150 unit. Subject connected modules are isolated from Mains via a Safety Extra-Low Voltage (SELV) wall transformer and subsequently, a DC/DC converter, optocouplers, and Ethernet communications transformer within the MP150 unit.

The MP150 unit incorporates two sections, an unisolated part and an isolated part. The unisolated part receives power via a 12 VDC @ 2.5 amp TUV, UL and CSA approved wall transformer (adapter). This adapter also internally connects Mains Earth to the negative terminal of the 12VDC supply. The MP150 unisolated part is also connected to the computer Mains Earth via the serial (USB) cable. The unisolated part contains a high isolation (4000 V peak) DC-DC converter which provides power to the isolated part. The isolated part transmits its data to the unisolated part via high isolation optocouplers and Ethernet transformer. See Appendix for the isolation description block diagram.

1. <u>Power Supply</u>:
    For 120 V or 240 V operation, CUL* and UL* and TÜV approvals, embedded IEC socket, BIOPAC P/N: AC100A, rated 120 - 240 VAC, 50 - 60Hz, 0.4 A (surge), output 12 V, 25W.

2. <u>Main Unit Enclosure</u>:
    Molded plastic, made of 'Polystyrene', Type BOPLA, color gray, minimum 3.0 mm thick, flammability rated CSA 0.6HB (for gray colors and minimum 1.6 mm thick) and UL 94HB (for gray colors and minimum 1.6 mm thick); shaped as shown. Consists of plastic shells, secured together by screws and integral channels.

3. <u>Main PWB</u>:
    UR construction and (subject circuit) spacings are as described in Appendix, three printed wire boards and one metal shield, each measures 10.1 cm by 17.9 cm,

secured to the rear panels by standoffs, screws, nuts and washers. Provided with the following components:

(a) Fuseholder and Fuse:
Fuseholder is C*, UR*, SEMKO, VDE, 'Littelfuse', P/N 345, rated 15 A, 250 VAC, shock safe type, PWB mount type. Fuse is C*, UL*, '3AG', P/N: AGC-2, rated 250 VAC, 2 Amp, fast blow. Note: Fuse rating and type is marked in a permanent manner adjacent to the fuse.

(b) DC-DC Converter:
(U206), Accepted, 'Power-One, Inc., P/N: DGP20S218, input: 9-18 VDC, 2160 mA, output: 5 VDC, 2500 mA, ±12 VDC, 310 mA. Rated for continuous 1500 VDC (4000 V pk) isolation input to output. Undergoes testing performed per methods set forth by VDE750, CSA 22.2 and IEC601-1.

(c) Optocouplers:
(U201, U203) Accepted, 'Hewlett-Packard', P/N HCPL 2630, rated 2500 VAC (rms) isolation input to output. Recognized under the component program of U.L. (File # E55361) for dielectric proof test.

4. Conditioning (Subject) Modules:
Conditioning Modules operate at Safety Extra-Low Voltage. Subject isolation from Mains is provided by the Wall Transformer (adapter) and subsequently by the MP150 unit internal DC/DC converter, optocouplers and Ethernet transformer.

Up to 16 modules may be provided. Power is provided to the modules through the DC- DC converter described above which limits the power output to maximum 25 W.

Molded plastic, made of 'Polystrene', type BOPLA, color gray, minimum 3.0 mm thick, flammability rated CSA 0.6HB (for gray colors and minimum 1.6 mm thick) and UL 94HB (for gray colors and minimum 1.6 mm thick); shaped as shown. Consists of plastic shells, secured together by screws and integral channels.

5. Subject Leads and Transducers:
Typically ECG type, actual may vary. Subject leads are constructed to prevent engagement with any part on the equipment that could be a risk of electric shock, fire, or injury to persons. Also, the equipment is only intended for use with professional supervision.

APPENDIX

Important Measurement Considerations

As a general laboratory instrument, the MP150 System can be used to monitor signals from various laboratory equipment or, alternatively, live subjects. Because of the MP150 construction, it is possible to inadvertently ground the subject when connecting other laboratory equipment to the MP150 System during subject monitoring.

WHEN MEASURING FROM SUBJECTS, DO NOT HAVE ANY OTHER LABORATORY EQUIPMENT CONNECTED TO THE MP150 ANALOG OR DIGITAL INPUT PORTS.

The MP150 System Analog/Digital ports (and UIM100) are part of the subject isolation circuit and thus can become accessible metal parts that may be incidentally grounded which would defeat the isolation provided by the internal DC to DC converter, optocouplers, and Ethernet transformer.

When connecting the MP150 system, via Conditioning Modules, to a subject, safety concerns often dictate the removal of all connections from mains powered or earthed equipment from the UIM100 module or other Conditioning Module.

If connections to other mains powered or earthed equipment are required while recording from subjects using the MP150 system, then those connections should be made via the INISO or OUTISO signal isolators, used in conjunction with the HLT100 module.

Figure 1. MP150 System Isolation Construction
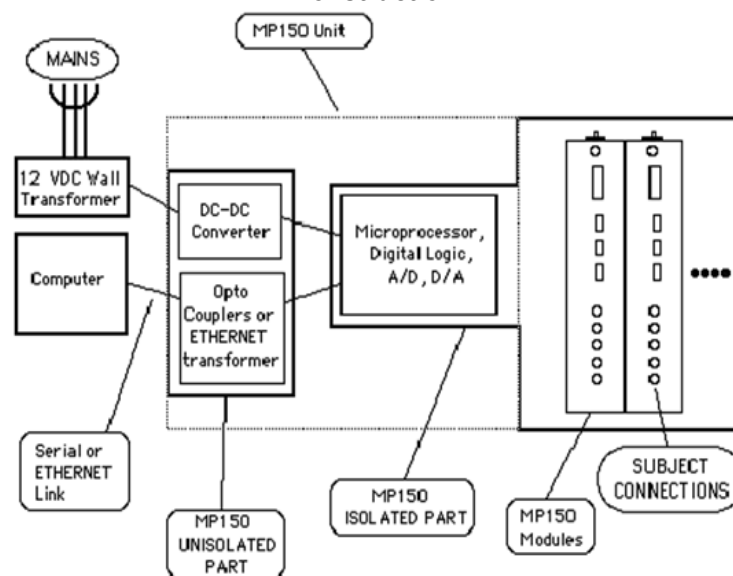
MP150 System Isolation Construction Notes (see Figure 1):

1. The SELV (TUV, CSA, UL) 12 VDC wall transformer adapter powers the DC-DC converters and the Unisolated Part of the optocoupler digital communications circuitry and Ethernet transformer. The DC-DC converter output powers the MP150 Isolated Part including the MP150 Conditioning Modules, where Subject Connections are made.
2. The Computer Serial (ETHERNET or USB) Link ground is connected to the MP150 Unisolated ground, which is connected to Mains Earth. Mains Earth is connected to the MP150 Unisolated ground via the 12 VDC wall transformer to provide an Earth connection (for Leakage Current Safety) when the MP150 is connected to either portable or non-portable computers.
3. The MP150 Unisolated Part and Isolated Part are linked by a high isolation DC-DC converter, two optocouplers, and one Ethernet transformer. All MP150 (Conditioning) Modules connect to the MP150 Isolated Part. The MP150 Isolated Part appears as an1800pF capacitor to Mains Earth.

Electromagnetic Compatibility Test Results

The following graph (Figure 2) illustrates the performance of the MP150 System for Conducted Emissions. The Limit lines indicate the not-to-exceed emission levels associated with EN55011 Class A and Class B.

Figure 2. MP150 Conducted Emissions
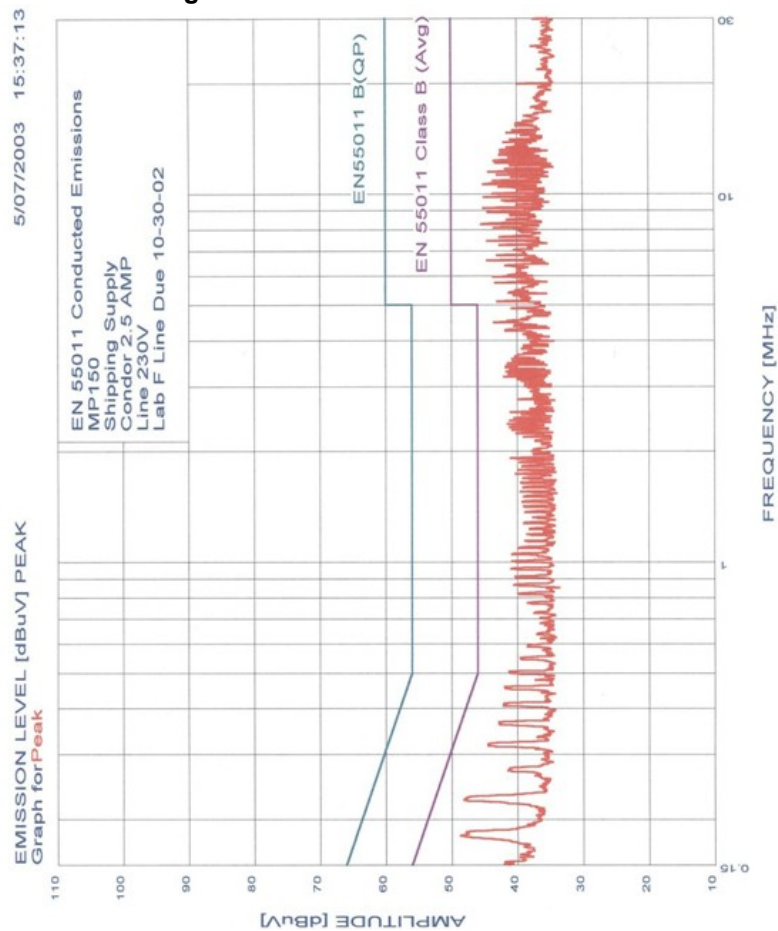
The following graphs (Figure 3) illustrate the performance of the MP150 System for Radiated Emissions. The Limit lines indicate the not-to-exceed emission levels associated with EN55011 Class A.

Figure 3. MP150 Radiated Emissions

120

MP150 Radiated Emissions (30-230 MHz)

MP150 Radiated Emissions (230-1000 MHz)
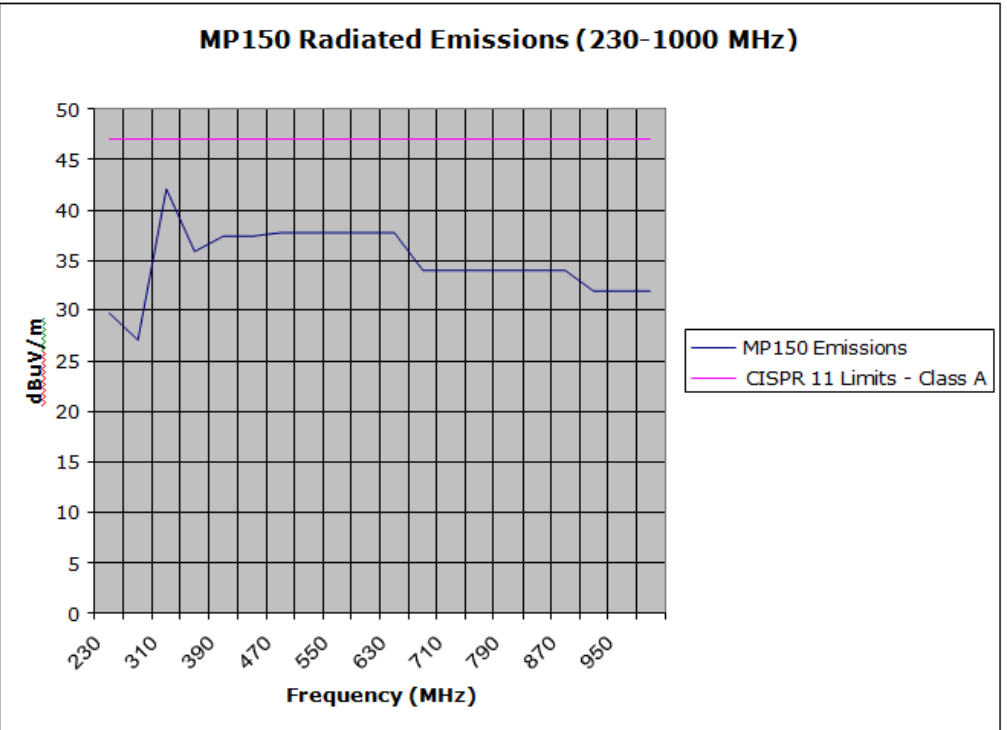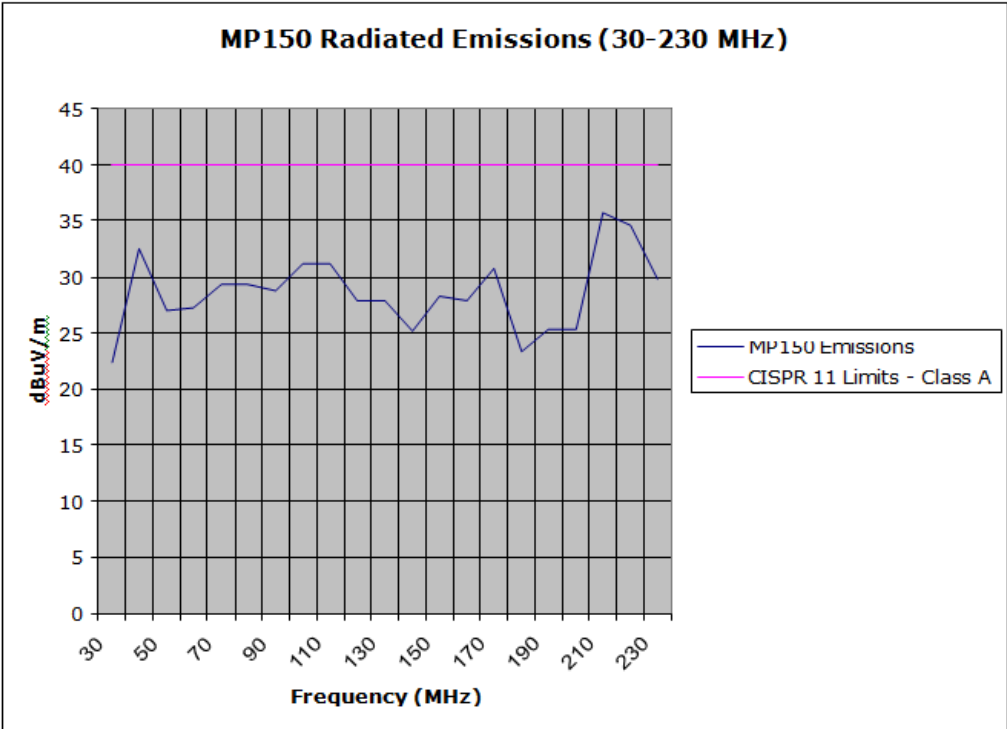
Factory Testing Procedures for Medical Safety

Dielectric Testing

The equipment at the conclusion of manufacture, before shipment, shall withstand for one second, without breakdown, the application of 2000 VDC between Live parts and Signal Input/Output parts. The same test is performed between Signal Input/Output parts and Floating Applied parts. The factory test is made at existing room temperature.

Leakage Current Testing

1) The equipment at the conclusion of manufacture, before shipment, shall permit a leakage current of no more than 8µA from the Floating Applied (Subject Connected) parts to
Earth, during normal system operation. The factory test may be made at existing room temperature. The test procedure is illustrated in Figure 4.

2) The equipment at the conclusion of manufacture, before shipment, shall permit a leakage current of no more than 100µA, resulting from the application of 120 VAC between Floating Applied (Subject Connected) parts and Signal Input/Output parts. Note that Signal Input/Output parts ground is connected to Mains Earth. The factory test may be made at existing room temperature. The test procedure is illustrated in Figure 5.

WARNING

The factory test(s) specified may present a hazard of injury to personnel and/or property and should only be performed by persons knowledgeable of such hazards and under conditions designed to minimize the possibility of injury.

Figure 4. Leakage Current Testing of MP 150 System
– Floating Applied Part to Mains Earth –
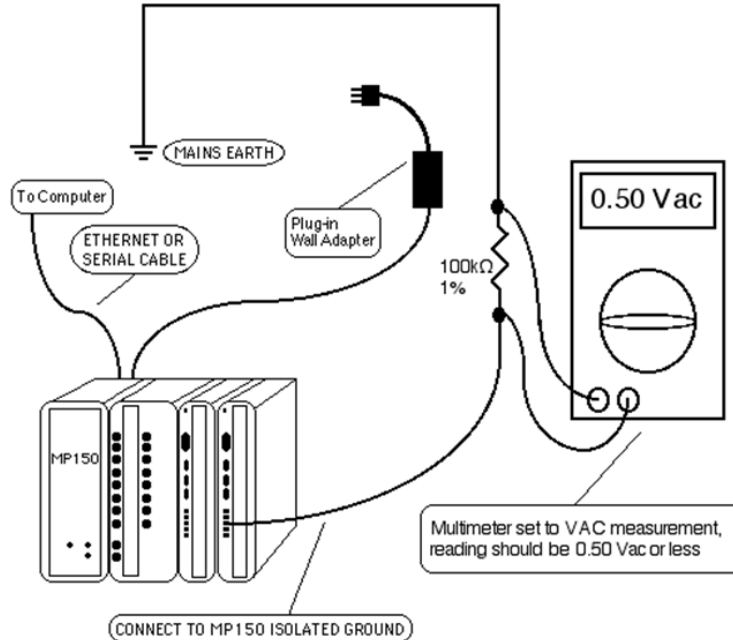
Testing Notes:
When testing for Leakage Currents the MP150 should be connected to the computer via the Ethernet or Serial (USB) Cable. Also, the wall transformer adapter must be connected to Mains power and the MP150 unit. Leakage current test should be performed at intervals coincident with general calibration procedures.

The MP150 Leakage Current (Floating Applied Part to Mains Earth) passes through the 100k Ohm resistor. The multimeter measures the voltage developed across the 100k Ohm resistor. Accordingly, the maximum measured voltage should be 0.80 VAC, which indicates a maximum leakage current of 8µA.

Figure 5. Leakage Current Testing of MP 150 System
– Floating Applied Part to Mains Line –
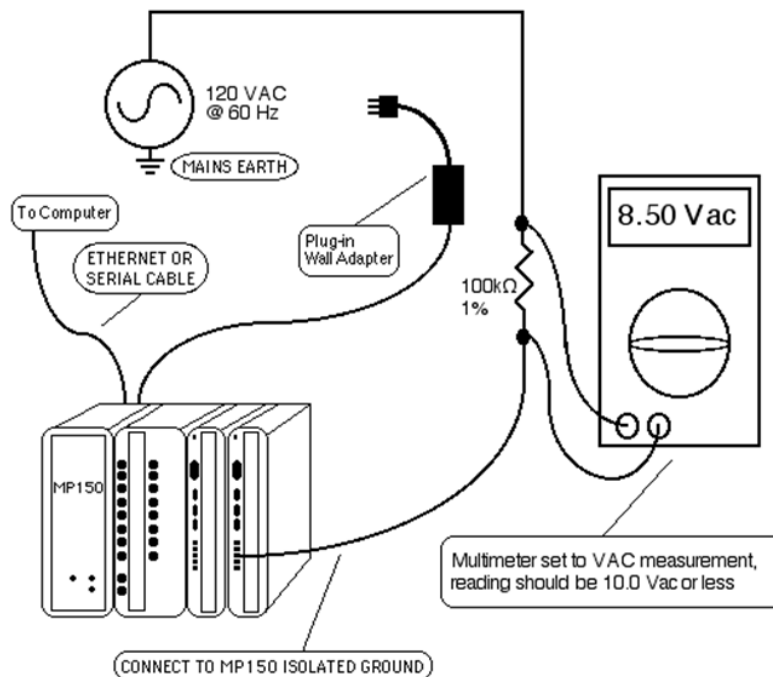
Testing Notes:
When testing for Leakage Currents the MP150 should be connected to the computer via the Ethernet or Serial (USB) Cable. Also, the wall transformer adapter must be connected to Mains power and the MP150 unit. Leakage current test should be performed at intervals coincident with general calibration procedures.

The MP150 Leakage Current (Floating Applied Part to Mains Line) passes through the 100k Ohm resistor. The multimeter measures the voltage developed across the 100k Ohm resistor. Accordingly, the maximum measured voltage should be 10.0 VAC, which indicates a maximum leakage current of 100µA.

Contact BIOPAC Systems, Inc. if you need
- **MP150 Schematic**
- **MP150 PWB Layout**
- **MP150 Product Catalog**

H. Subject Recruiting Material

Recruitment Email:
Dear Colleagues,

The researchers in RHC are interested in establishing the effects of localized temperature changes on vigilance performance and whether this relationship is moderated by individual stressor appraisals. I am looking for volunteers between the ages of 18 and 45 to take part in a study in which vigilance performance data, physiological data, and individual stressor appraisal data will be collected.

Should you volunteer to participate in this study, the time requirement for each volunteer subject is anticipated to be a maximum of 1 session lasting 60-90 minutes. No monetary compensation is being offered for participation. I have slots for 54 subjects available right now, and will take volunteers on a first come, first served basis.

Participants, ages 18-45, must have normal or corrected-to-normal visual acuity and depth perception.

If you are interested in participating or for more information, please email Ms. Jessica Pack, Jessica.Pack.ctr@wpafb.af.mil, or Ms. Justine Jeroski, Justine.Jeroski@afit.edu.

Thank you for your time.

V/R,
Jessica Pack

I. FLIR T400 Technical Specifications

FLIR T400 Technical Specifications

Imaging Performance

Field of view/min focus distance	25°x19° / 0.4 m (1.31 ft.)
Thermal sensitivity (NETD)	0.05°C @ +30° (+86°F) / 50mK
Detector type	Focal Plane Array (FPA), uncooled microbolometer
IR resolution	320 x 240
Spectral range	7.5 to 13 µm
Digital zoom and pan/focus	1-8X continuous/auto & manual focus
IFOV (with 25° lens)	1.36 mRad

Image Presentation

Image modes	Thermal, Visual, Thermal Fusion
Thermal Fusion	Merging of visible light and IR image (Interval, Above/Below)
FLIR Fusion	Picture in Picture (PIP) resizable and movable
Image annotation	Voice annotation (60 seconds) Text from touch screen soft keys Text from predefined list Sketch Image markers on IR/Visual
Display	Built-in touch-screen LCD display, 3.5 in.
Visible light camera resolution	1280 x 1024 (1.3 megapixels)
Video lamp	1000 CD

Measurement

Object temperature ranges	–20°C to +120°C (–4˚F to +248˚F), 0°C to 350°C (32°F to 662°F), Optional up to +1200°C (+2192°F)
Accuracy	±2˚C (±3.6˚F) or ±2% of reading
Measurement modes/analysis	5 Spotmeters, 5 Box areas, Isotherm, Difference temperature function, Auto hot/cold spot
Alarms	Audible/Visual alarms (above/below) on spotmeters, area boxes and difference temperature
Set-up controls	Mode selector, color palettes (BW, BW inv, Iron, Rain, Rain HC, Bluered), configure info to be shown in image, local adaptation of units, language, date and time formats, and image gallery
Emissivity table	Emissivity list of predefined materials
Measurement corrections	Reflected ambient temperature and emissivity correction

Image Storage

Digital storage type/capacity	Removable SD Memory Card/1000+ JPEG images
Image storage mode & formats	IR/visible light, simultaneous storage of IR and visible images, standard JPEG, MPEG4 video (non-rad. video)

Laser LocatIR™

Classification/Type	Class 2/Semiconductor AlGaInP Diode Laser: 1mW/635 nm (red)

Power Source

Battery type	Rechargeable Lithium-Ion battery
Battery operating time	4 hours +
Battery charging	2 bay charging system, 10-16 V input. Charging status indicated by LED's
AC operation	AC adapter, 90-260 VAC input. 12 V output to camera
Voltage	11-16 VDC
Power management	Automatic shut down and sleep mode after settable time

Environmental

Operating temperature range	-15°C to +50°C (5°F to 122°F)
Storage temperature range	-40°C to +70°C (-40°F to +158°F)
Humidity	95% relative humidity +25°C to +40°C (+77°F to +104°F) non condensing
Water and dust resistant (encapsulation)	IP 54, IEC 529
Shock	25G, IEC 68-2-29
Vibration	2G, IEC 68-2-6

Physical Characteristics

Weight	0.88 kg (1.94 lb.)
Size (L x W x H)	106 x 201 x 125 mm (4.2 x 7.9 x 4.9 in.), with lens pointing forward
Tripod mounting	1/4" - 20

Interfaces

USB (cable included)	Image transfer to PC
Video output	NTSC Video

Software

QuickReport™	Included
Reporter™ 8 (Microsoft® Word based)	Optional

Camera includes:

- IR camera with F 1.3 25° lens, image frequency 30Hz
- Integral visible light camera with lamp
- Transport case
- Camera Lens Cap
- Battery
- 2-bay battery charger
- Headset, 3.5 mm plug
- Video Cable
- USB cable Std A <-> Mini B, 2 m/6.6 ft.
- SD Memory Card
- Sun Shield
- Stylus Pen
- User documentation CD-ROM, 21 languages
- Power supply
- Getting Started guide

Interchangeable lenses/options

- Optional Add-on optics, Telephoto lens, 12°
- Optional Add-on optics, Wide angle lens, 45°
- High temperature option (up to +1200 °C/+2192 °F)
- 12 volt auto adapter
- Hip/belt mounted camera holster
- Neckstrap
- USB-A for memory stick

From Left to right: USB mini for PC image download, 4 pole audio for voice annotation, NTSC video, USB-A for memory stick image transfer

FLIR
THE GLOBAL LEADER IN INFRARED CAMERAS

Holster for Portability and Easy Access to Camera

Target Illuminator and 1.3 Mega Pixel Visual Camera

Tiltable Optics Reduces Back and Arm Strain

Touch Screen Text/Sketch Functionality

- Thermal Fusion Functionality
- Interchangeable Optics
- 1.3 MegaPixel Visual Camera
- Automatically Associates the Visual and Thermal JPEG Images
- Includes FREE QuickReport Software for Analysis & Reporting
- Compatible with Optional Microsoft Word®-Based ThermaCAM Reporter Software w/Spell Check
- Removable SD/Memory Card, USB & Video Out
- Onscreen Thumbnail Image Gallery
- In camera Emissivity Tables, 5 Temperature Spots & Delta T Functionality
- Touch Screen Technology Adds Markers, Draws, Sketches
- Auto or Manual Focus with 8x Continuous Digital Zoom
- Auto Hot/Cold Spot & Audible/Visual Alarms
- Large 3.5" Color Touch-screen LCD
- High Thermal Sensitivity for Maximum Temperature Accuracy
- Voice, Text & Sketch Annotation
- Built-in LaserLocatIR™
- Long 4-hour Battery with In-Camera Charging or Car Charger
- Optics head & display screen are independently rotatable for optimum viewing

Razor-Sharp Image Quality

The T400 delivers 320 x 240 IR resolution — that's 76,800 pixels. This, combined with FLIR's exclusive Advanced Signal Processing, reduces image "noise" and produces razor-sharp thermal images four times the resolution of competing brands with 160 x 120 resolution. Image, as they say, is everything!

Advanced Optics

The T400 offers both Auto and Manual Focus, making it easy for anyone to take razor-sharp thermal images and helping those new to infrared from taking out-of-focus images. A powerful one-touch 8x continuous digital zoom lets you zero-in to the optimal view, whereas other cameras deliver only preset zooms.

Interchangeable Lenses

The T400 comes with a built-in standard 25° lens with the option of adding on a 45° wide angle or 15° telephoto lens.

Thumbnail Image Gallery

An easy-to-access thumbnail image gallery is available to help you quickly review your saved thermal images to find the one you want – a massive convenience and time saver!

Touch Screen Technology

Touch Screen technology lets you save text, markers or even sketches right with your thermal images, directly on the camera right from the work site. It's like having a note and sketch pad with you every time you turn on the camera – increasing your productivity and the quality of your reports.

1.3 Mega Pixel Visual Camera

Capture visible images at the same time you capture your thermal image with a built-in 1.3 mega pixel digital camera. Includes a target illuminator for low light situations. You can draw markers using Touch Screen technology that works directly on the visual image.

Maximum Connectivity Options: SD/Memory Card, Audio, Video & USB

Thousands of images can be stored to a standard removable SD Memory Card. Use the Audio port to connect a headset and record voice comments while you work with the camera. Voice comments are stored with the IR image and can be played back using FLIR QuickReport or FLIR Reporter. A standard Video port lets you display your images in real-time with any number of off-the-shelf video displays – ideal when working with a team or showing thermal output to customers, clients or superiors. A standard USB port allows for automatic image download from the camera using FLIR QuickReport.

In-Camera Radiometric JPEG Image Format

The infrared image is more than just a picture. All temperature data, object parameters, analysis tools, voice and text comments are stored with the infrared image, allowing for advanced post-processing and report writing using QuickReport (included) or FLIR's Microsoft® Word®-Based Reporter. Add voice comments in the field using a headset. Add text annotation using a Touch Screen keypad or a Text Comment File containing a list of preset values. The T400 JPEG image format combined with FLIR's versatile PC software creates a powerful and unique Thermography system that eases data collection in the field.

MicroSoft® Word®-compatible Software with Spell Check

The T400 comes with FREE QuickReport analysis and reporting software. Optional Reporter software allows you to transfer fully radiometric – or "live" – images into Word so you can go back and edit reports, adjust temperature span or change color palettes at any time – critical functionality if you intend to email reports to peers, customers or superiors or simply if you want to run Spell Check!

Onscreen Emissivity Tables,

Up To 5 Temperature Spots & Delta T Functionality

Temperature difference is the most frequently used measurement parameter for assessing the condition of electrical components and other plant assets. Accurate temperature difference information could determine if the color variation detected with the camera represents a normal operating condition or a problem that is about to start a fire.

The T400 makes this information easy to see and communicate with the Delta Temperature mode. Just place a reference spot on a target operating at normal temperature and another on the target with elevated temperature. The Delta Temperature Function immediately displays the difference between these two targets on the image making it easy for you to diagnose the severity of the problem. The image can then be stored with these measurements and incorporated into the report. It's the easiest and fastest way to diagnose and report your IR findings.

Auto Hot/Cold Spot & Audible/Visual Alarms

Seeing the hottest or coldest spot on the thermal image is often a critical requirement. FLIR's advanced in-camera algorithms make this normally time-consuming task a breeze. You can even pre-set temperature triggers to sound audible or show visible alarms, and the advanced in-camera tools can identify overheating circuits, missing insulation, mechanical failures, water intrusion leaks and literally "sound off" to alert you to a potential problem with the target you are scanning.

Now with FLIR THERMAL FUSION!

FLIR's new FUSION functionality allows for easier identification and interpretation of infrared images. This advanced technology enhances the value of an infrared image by allowing you to overlay it directly over the corresponding visible image. This functionality combines the benefits of both the infrared image and visual picture at the push of a button. The T400 camera does this in real-time and the overlay function can be easily adjusted to suit any application such as electrical surveys, building diagnostics, and mechanical inspections.
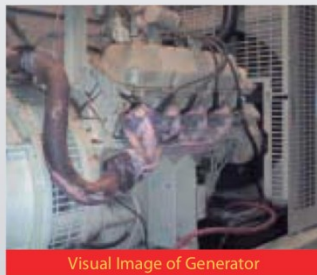
Visual Image of Generator
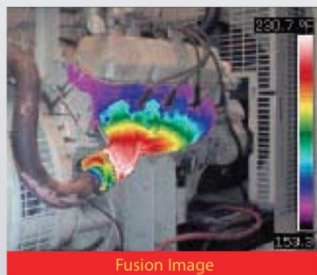
Fusion Image
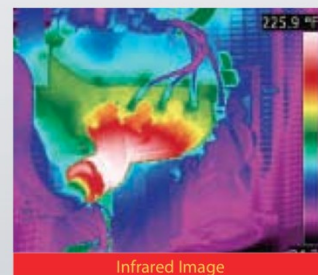
Infrared Image

Appendix B – Experimental Procedure Checklist

Experiment Procedure Checklist

- ☐ Prior to next participant's arrival:
  - o Research team will set up the room, turn on all equipment, lay out necessary informed consent document (ICD) and surveys, and write corresponding participant number on each.

- ☐ Participant arrives at scheduled time to Building 33, Room 023.

- ☐ Introduction to the research team and a briefing on the study and its goals will be provided.

- ☐ An explanation of the ICD will be given to the participants. They will then be asked to read and sign it.

- ☐ The vigilance task they will be asked to complete will be explained to them and the possible temperature changes that they could experience while sitting in the pod. The figure below will be shown for examples of critical and neutral stimuli.

Critical Event (Collision Path)	Neutral Event (Safe) Stimuli
Clockwise Flight Paths	
Counter-clockwise Flight Paths	
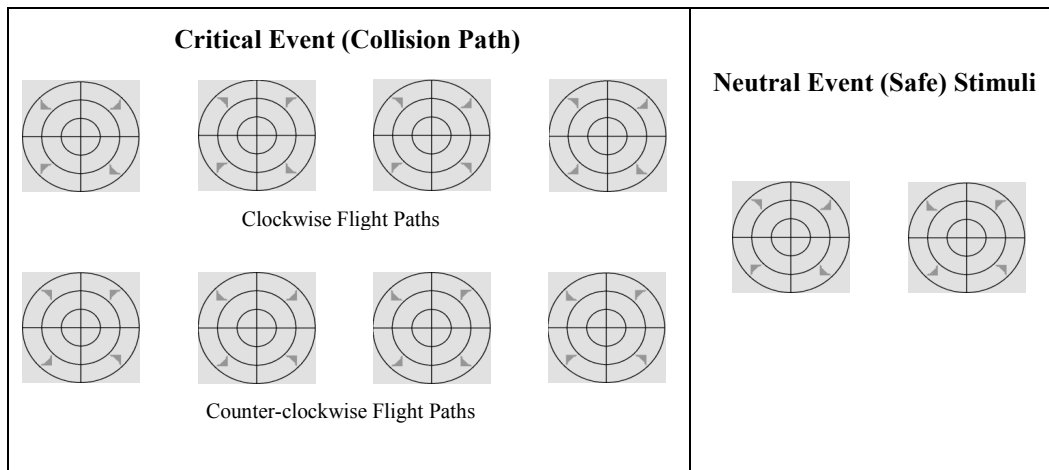
- ☐ Visual acuity, depth perception, and dominant hand tests will be administered.
  - o Vision standards are 20/20 vision (at least 3 in the line of 5 correct) and all four pie slices on page 5. The Edinburgh Handedness Inventory will be used to determine which hand is the participant's dominant one (used as the one to hold the clicker).
  - o Fill in participant data sheet with test results, participant's gender, and age.

- ☐ The participant will be asked to fill out a stress questionnaire.

☐ The participant will be asked to turn off any phone or electronic device present and to remove any coats, jackets, scarves.

☐ ECG electrodes will be placed on the participant's chest and will require clothing covering the area to be lifted or removed to allow for proper placement. A gender-consistent restroom with the assistance of an individual having the same gender as the participant will be available for this fitting. Once the electrodes are fit, the participant will be able to return their clothing to its proper position on their torso before leaving the restroom. (Upper right – white, Lower right – black, Lower left – red)

☐ They will be asked to sit in the pod.

☐ Participant's forehead and area around their eyes will first be swabbed with an alcohol wipe. Then cerebral oximetry sensors will first be applied to the participant's body via an adjustable headband place high on the forehead. Care will be taken to avoid placing over hair or on top of sinus cavities. Signal strength and accuracy will be tested.

☐ EOG electrodes will be applied to the participant's body. ECG and EOG wires will be connected to their respective device and tested for a valid signal.

☐ One of the five thermocouples will be taped to the outside of the participant's shirt and rest under the thermoelectric blanket. The other four will have been previously place along the top side of the pad underneath the participant.

☐ The thermoelectric blanket will be placed over the participant and a clicker will be handed to them to hold in their dominant hand.

☐ The participants will be given a 5 minute training/practice period to familiarize themselves with the vigilance task. During which they must show that they correctly understand and can successfully complete the task.

☐ Upon successful completion of the practice period, the task will be reset and the shield of the pod closed. They will then be asked to press the clicker to begin the

40-minute vigilance task. For participants in the hot or cold condition, the thermoelectric pad and blanket will be switched on by the researchers at the 20-minute mark. The task will automatically end when the time is complete.

☐ The thermoelectric blanket will be removed and the clicker returned.

☐ The EOG electrodes and CO sensors will be removed and all wires disconnected from the participant.

☐ The participant will be allowed to exit the pod.

☐ ECG electrodes that were placed on their chest will be removed in a gender-consistent restroom with the assistance of an individual having the same gender as the participant.

☐ The participant will be asked to complete a manipulation check questionnaire.

☐ A final debriefing will be provided and the participant will be able to ask any further questions they may have.

☐ After the participants departure:
  o Research team will compile and store all data, turn on off equipment, clean up the room, and secure any necessary documents.

Appendix C – MATLAB Code

```matlab
% Code to analyze performance data for HF paper.
% AFIT Thesis
% Justine Jeroski
% 2014


clear all, close all
clc

% change directory to where the data is stored
cd I:\setup\Desktop\Justine' 'Thesis\MATLAB\


subjects = 33; % set the number of subjects

% specifiy the last row of the excel spreadsheet of responses for each
subject
endNumHits = [166, 168, 170, 168, 168, 168,...
    166, 182, 169, 168, 173, 200,...
    166, 167, 173, 172, 164, 168,...
    166, 167, 167, 165, 173, 167,...
    164, 165, 167, 183, 167, 167,...
    169, 186, 187];

% specifiy the last row of the excel spreadsheet of all signals for
each subject
endNumNeu = [1323, 1345, 1344, 1348, 1266, 1359,...
    1311, 1321, 1351, 1353, 1361, 1360,...
    1349, 1355, 1358, 1317, 1314, 1346,...
    1351, 1345, 1289, 1328, 1338, 1266,...
    1346, 1353, 1256, 1349, 1352, 1308,...
    1339, 1318, 1370];

% save averages for all time periods for each subject
hitRates = zeros(subjects, 20);
FArates = zeros(subjects, 20);
Aprimes = zeros(subjects, 20);

for s = 1:subjects
    % read in the response data
    disp(['reading performance data from subject ' ,num2str(s),'....'])
    starttimeH = xlsread('Performance_Data_For_Matlab.xls', s, 'A2');
    exptimeH  = xlsread('Performance_Data_For_Matlab.xls', s,
['A4:A',num2str(endNumHits(s))]);
    responses  = xlsread('Performance_Data_For_Matlab.xls', s,
['C4:C',num2str(endNumHits(s))]);
    % convert exp time to running time
    starttimeH = ones(length(exptimeH), 1) * starttimeH;
    timeH = exptimeH - starttimeH;

    % read in the neutral signal data
    starttimeN = xlsread('Performance_Data_For_Matlab_Neutrals.xls', s,
'B2');
```

```matlab
    exptimeN    = xlsread('Performance_Data_For_Matlab_Neutrals.xls', s,
['B2:B',num2str(endNumNeu(s))]);
    neutrals    = xlsread('Performance_Data_For_Matlab_Neutrals.xls', s,
['C2:C',num2str(endNumNeu(s))]);
    % convert exp time to running time
    starttimeN = ones(length(exptimeN), 1) * starttimeN;
    timeN = exptimeN - starttimeN;

    c=1;
    for t = 0:120:2280
        % calculate the hit rate
        responsesintime = responses(timeH >= t & timeH < (t+600),:);
        numofHits = length(responsesintime (responsesintime == 3));
        numofMisses = length (responsesintime (responsesintime == 4));
        hitrate = numofHits/(numofHits + numofMisses);
        % calculate the false alarm rate
        singalsintime = neutrals(timeN >= t & timeN < (t+600),:);
        numofFA = length (responsesintime (responsesintime == 10));
        numofNeu = length (singalsintime (singalsintime == 78));
        FArate = numofFA/numofNeu;
        % calculate A prime for each period
        Aprime = 0.5 +((hitrate-FArate)*(1+hitrate-
FArate))/((4*hitrate)*(1-FArate));

        % averages over time periods
        hitRates(s,c)= hitrate;
        FArates(s,c) = FArate;
        Aprimes(s,c) = Aprime;

        c=c+1;
    end
    t = 0;

    disp 'done'
end

% sort out the averages by temperature
% hit rates
hothitRates = hitRates(1:3:31,:);
coldhitRates = hitRates(2:3:32,:);
neutralhitRates = hitRates(3:3:33,:);
% false alarm rates
hotFArates = FArates(1:3:31,:);
coldFArates = FArates(2:3:32,:);
neutralFArates = FArates(3:3:33,:);
% A' values
hotAprimes = Aprimes(1:3:31,:);
coldAprimes  = Aprimes(2:3:32,:);
neutralAprimes = Aprimes(3:3:33,:);

% preallocate for speed
% hit rates avgs
hothitRateAvgs = zeros (1,20);
coldhitRateAvgs = zeros (1,20);
```

```matlab
neutralhitRateAvgs = zeros (1,20);
% false alarm rates avgs
hotFArateAvgs = zeros (1,20);
coldFArateAvgs = zeros (1,20);
neutralFArateAvgs = zeros (1,20);
% A' values avgs
hotAprimesAvgs = zeros (1,20);
coldAprimesAvgs = zeros (1,20);
neutralAprimesAvgs = zeros (1,20);
% hit rate error
hotEhit = zeros (1,20);
coldEhit = zeros (1,20);
neutralEhit = zeros (1,20);
% false alarm rate error
hotEFA = zeros (1,20);
coldEFA = zeros (1,20);
neutralEFA = zeros (1,20);
% A' value error
hotEAp = zeros (1,20);
coldEAp = zeros (1,20);
neutralEAp = zeros (1,20);

i=1;
for p = 1:20
    % average hit rates across subjects
    hothitRateAvgs(1,i) = mean(hothitRates(:,p));
    coldhitRateAvgs(1,i) = mean(coldhitRates(:,p));
    neutralhitRateAvgs(1,i) = mean(neutralhitRates(:,p));

    % average false alarm rates across subjects
    hotFArateAvgs (1,i) = mean(hotFArates(:,p));
    coldFArateAvgs (1,i) = mean(coldFArates(:,p));
    neutralFArateAvgs (1,i) = mean(neutralFArates(:,p));

    % average A' values across subjects
    hotAprimesAvgs (1,i) = mean(hotAprimes(:,p));
    coldAprimesAvgs (1,i) = mean(coldAprimes(:,p));
    neutralAprimesAvgs (1,i) = mean(neutralAprimes(:,p));

    % standard error calcuations for error bars
    hotEhit (1,i) = std(hothitRates(:,p))/sqrt(11);
    coldEhit (1,i) = std(coldhitRates(:,p))/sqrt(11);
    neutralEhit (1,i) = std(neutralhitRates(:,p))/sqrt(11);

    hotEFA (1,i) = std(hotFArates(:,p))/sqrt(11);
    coldEFA (1,i) = std(coldFArates(:,p))/sqrt(11);
    neutralEFA (1,i) = std(neutralFArates(:,p))/sqrt(11);

    hotEAp (1,i) = std(hotAprimes(:,p))/sqrt(11);
    coldEAp (1,i) = std(coldAprimes(:,p))/sqrt(11);
    neutralEAp (1,i) = std(neutralAprimes(:,p))/sqrt(11);

    i=i+1;
end
```

```matlab
% set x values for plot (# of time periods)
periods = 1:20;

% plot mean mean hit rate over periods of watch
figure
errorbar(periods,neutralhitRateAvgs,neutralEhit,':kp',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hothitRateAvgs,hotEhit,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',8)
errorbar(periods,coldhitRateAvgs,coldEhit,'-.ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
%vertical line at the tempearture change
xline = [10.5 10.5];
yline = [0.6 0.9];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14); ylabel ('Percent
Correct Detection','fontsize',14)
legend ('Neutral','Hot','Cold','Location','SouthEast');
set(gca,'YTick',0.60:0.05:0.90);
set(gca,'YTickLabel',{'60%','65%', '70%', '75%', '80%', '85%', '90%'});
set(gca,'XTick',1:20)
set(gca,'XTickLabel',{'0-2', '2-4', '4-6', '6-8', '8-10', '10-12', '12-
14', '14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});
axis ([0 21 .60 .90])

% plot trend lines for hit rate graph
% hot condition, first half
x = 1:0.5:10.5; % set x values for first half
y = -0.0063055 * x + 0.86429;
plot (x, y, 'r', 'LineWidth', 3)
% cold condition, first half
y = -0.0039734 * x + 0.79333;
plot (x, y, 'LineWidth', 3)
% neutral condition, first half
y = -0.010797 * x + 0.79135;
plot (x, y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 10.5:0.5:20; % set x values for second half
y = -0.0056561 * x + 0.89667;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = 0.0032189 * x + 0.75954;
plot (x,y, 'LineWidth', 3)
% neutral condition, second half
y = 0.014233 * x + 0.53705;
plot (x,y, 'g', 'LineWidth', 3)

% plot mean mean hit rate over periods of watch
figure
```

```matlab
errorbar(periods,neutralFArateAvgs,neutralEFA,':kp',...
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotFArateAvgs,hotEFA,'-ks',...
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',10)
errorbar(periods,coldFArateAvgs,coldEFA,'-.ko',...
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
%vertical line at the tempearture change
xline = [10.5 10.5];
yline = [0 0.018];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14); ylabel ('False Alarm
Rate','fontsize',14)
legend ('Neutral','Hot','Cold','Location','NorthEast');
set(gca,'YTick',0:0.002:0.018);
set(gca,'YTickLabel',{'0%','0.2%', '0.4%', '0.6%', '0.8%', '1%',...
'1.2%','1.4%','1.6%','1.8%'});
set(gca,'XTick',1:20)
set(gca,'XTickLabel',{'0-2', '2-4', '4-6', '6-8', '8-10', '10-12', '12-
14', '14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});
axis ([0 21 0 0.018])

% plot trend lines for false alarm graph
% hot condition, first half
x = 1:0.5:10.5; % set x values for first half
y = -0.0002511 * x + 0.0083002;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, first half
y = -5.1524e-06 * x + 0.0086653;
plot (x,y, 'LineWidth', 3)
% neutral condition, first half
y = -0.00053064 * x + 0.014173;
plot (x,y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 10.5:0.5:20; % set x values for second half
y = -0.00018977 * x + 0.0059551;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = -0.00067617 * x + 0.016117;
plot (x,y, 'LineWidth', 3)
% neutral conidtion, second half
y = -6.818e-05 * x + 0.0080086;
plot (x,y, 'g', 'LineWidth', 3)



% Code to analyze cerebral oximetry data for HF paper.
% AFIT Thesis
% Justine Jeroski
% 2014

clear all, close all
clc
```

```matlab
% change directory to where the data is stored
cd I:\setup\Desktop\Justine' 'Thesis\MATLAB\

subjects = 33; % set the number of subjects

% specify the last row of the excel spreadsheet for each subject
endNum = [467, 468, 467, 465, 465, 468,...
    467, 465, 467, 468, 469, 467,...
    465, 467, 468, 468, 468, 465,...
    466, 468, 466, 468, 467, 467,...
    465, 468, 467, 467, 468, 466,...
    468, 465, 467];

% preallocate for speed
saveleftavgs = zeros(subjects, 19);
saverightavgs = zeros(subjects, 19);

% for each subject, get average percent change rSO2 values for right
and left hemisheres
for s = 1:subjects
    % read in the data for the experimental session for each subject
    disp(['reading CO data from subject ' ,num2str(s),'....'])
    starttime = xlsread('Excel_ExperimentOnly_CO.xls', s, 'B3');
    exptime = xlsread('Excel_ExperimentOnly_CO.xls', s,
['B3:B',num2str(endNum(s))]);
    rawleftrSO2 = xlsread('Excel_ExperimentOnly_CO.xls', s,
['F3:F',num2str(endNum(s))]);
    rawrightrSO2 = xlsread('Excel_ExperimentOnly_CO.xls', s,
['Q3:Q',num2str(endNum(s))]);

    % time equations
    time = exptime - starttime; % convert from time of day to running
exp time
    time = time.*86400; % convert time to seconds (24 hrs x 60 min x 60
sec)=86400

    % baseline the left and right cerebral oxygen saturation values
    % left
    leftbaseline = mean(rawleftrSO2(time < 120,:));
    PCleftrSO2 = ((rawleftrSO2 - leftbaseline)./leftbaseline).*100;
    %right
    rightbaseline = mean(rawrightrSO2(time < 120,:));
    PCrightrSO2 = ((rawrightrSO2 - rightbaseline)./rightbaseline).*100;

    % determine average left and right percent change(PC) rSO2 values
for each time period
    i=1;
    for t = 120:120:2280
        avgPCleftrSO2 = mean(PCleftrSO2(time >= t & time < t + 120,:));
        avgPCrightrSO2 = mean(PCrightrSO2(time >= t & time < t +
120,:));
        % save averages
        saveleftavgs (s,i) = avgPCleftrSO2;
```

136

```matlab
        saverightavgs (s,i) = avgPCrightrSO2;
        i = i + 1;
    end
    t = 120;
    disp 'done'
end

% sort out the averages by temperature
% left
hotleftavgs = saveleftavgs(1:3:31,:);
coldleftavgs = saveleftavgs(2:3:32,:);
neutralleftavgs = saveleftavgs(3:3:33,:);
% right
hotrightavgs = saverightavgs(1:3:31,:);
coldrightavgs = saverightavgs(2:3:32,:);
neutralrightavgs = saverightavgs(3:3:33,:);

% preallocate for speed
% left
hotmeanleft = zeros (1,19);
coldmeanleft = zeros (1,19);
neutralmeanleft = zeros (1,19);
% right
hotmeanright = zeros (1,19);
coldmeanright = zeros (1,19);
neutralmeanright = zeros (1,19);
% left
hotleftSE = zeros (1,19);
coldleftSE = zeros (1,19);
neutralleftSE = zeros (1,19);
% right
hotrightSE = zeros (1,19);
coldrightSE = zeros (1,19);
neutralrightSE = zeros (1,19);

i=1;
for p = 1:19
    % average rSO2 values across subjects
    % left
    hotmeanleft(1,i) = mean(hotleftavgs(:,p));
    coldmeanleft(1,i) = mean(coldleftavgs(:,p));
    neutralmeanleft(1,i) = mean(neutralleftavgs(:,p));
    % right
    hotmeanright (1,i) = mean(hotrightavgs(:,p));
    coldmeanright (1,i) = mean(coldrightavgs(:,p));
    neutralmeanright (1,i) = mean(neutralrightavgs(:,p));

    % standard error calcuations for error bars
    % left
    hotleftSE (1,i) = std(hotleftavgs(:,p))/sqrt(11);
    coldleftSE (1,i) = std(coldleftavgs(:,p))/sqrt(11);
    neutralleftSE (1,i) = std(neutralleftavgs(:,p))/sqrt(11);
    % right
    hotrightSE (1,i) = std(hotrightavgs(:,p))/sqrt(11);
```

```matlab
    coldrightSE (1,i) = std(coldrightavgs(:,p))/sqrt(11);
    neutralrightSE (1,i) = std(neutralrightavgs(:,p))/sqrt(11);

    i=i+1;
end

% set x values for plot (# of time periods)
periods = 1:19;

% plot mean rSO2 values for left and right hemispheres over periods of
watch
% hot condition
figure
errorbar(periods,hotmeanleft,hotleftSE,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotmeanright,hotrightSE,':ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
% vertical line at the tempearture change
xline = [9.5 9.5];
yline = [0 5];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent rSO2 Change (Hot Condition)','fontsize',14);
legend ('Left','Right','Location','SouthEast')
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for hot condition graph
% left, first half
x = 1:0.5:9.5; % set x values for first half
y = -0.09775 * x + 1.8293;
plot (x,y, 'g', 'LineWidth', 3)
% right, first half
y = -0.079355 * x + 1.3302;
plot (x,y, 'LineWidth', 3)
% left, second half
x = 9.5:0.5:19; % set x values for second half
y = 0.27473 * x - 1.2365;
plot (x,y, 'g', 'LineWidth', 3)
% right, second half
y = 0.26569 * x - 1.3668;
plot (x,y, 'LineWidth', 3)

% cold condition
figure
errorbar(periods,coldmeanleft,coldleftSE,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,coldmeanright,coldrightSE,':ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
```

```matlab
% vertical line at the tempearture change
xline = [9.5 9.5];
yline = [-2 5];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent rSO2 Change (Cold Condition)','fontsize',14);
legend ('Left','Right')
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for cold condition graph
% left, first half
x = 1:0.5:9.5; % set x values for first half
y = -0.028423 * x + 3.1978;
plot (x,y, 'g', 'LineWidth', 3)
% right, first half
y = -0.046121 * x + 2.3614;
plot (x,y, 'LineWidth', 3)
% left, second half
x = 9.5:0.5:19; % set x values for second half
y = 0.11763 * x - 1.2235;
plot (x,y, 'g', 'LineWidth', 3)
% right, second half
y = 0.066346 * x - 0.69751;
plot (x,y, 'LineWidth', 3)

% neutral condition
figure
errorbar(periods,neutralmeanleft,neutralleftSE,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,neutralmeanright,neutralrightSE,':ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
% vertical line at the tempearture change
xline = [9.5 9.5];
yline = [-1.5 3.5];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent rSO2 Change (Neutral Condition)','fontsize',14);
legend ('Left','Right','Location','SouthWest')
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for neutral condition graph
% left, first half
x = 1:0.5:9.5; % set x values for first half
y = -0.032011 * x + 2.2596;
plot (x,y, 'g', 'LineWidth', 3)
% right, first half
```

```matlab
y = -0.18549 * x + 2.557;
plot (x,y, 'LineWidth', 3)
% left, second half
x = 9.5:0.5:19; % set x values for second half
y = -0.018309 * x + 2.2066;
plot (x,y, 'g', 'LineWidth', 3)
% right, second half
y = -0.15838 * x + 3.0373;
plot (x,y, 'LineWidth', 3)



% Code to analyze ECG data for HF paper.
% AFIT Thesis
% Justine Jeroski
% 2014

clear all, close all
clc

% change directory to where the data is stored
cd I:\setup\Desktop\Justine' 'Thesis\MATLAB\

subjects = 33; % set the number of subjects

% read in flags (start and end of critical periods) for EOG/ECG data.
disp 'reading physiology flags spreadsheet....'
flags = xlsread('Physiology Flags.xls', 1,
['H4:H',num2str(subjects+3)]);
disp 'done'
% convert all times to minutes
flags = flags / 60;

% preallocate for speed what I want to save
heartrates = zeros(subjects, 19);
baseheartrates = zeros(subjects, 1);
percentchangeHR = zeros(subjects,19);
percentchangeCVRR = zeros (subjects, 19);

% read in the threshold values for each subject
threshold = xlsread('ECG_Thresholds.xls', 1,
['B3:B',num2str(subjects+2)]);

for s = 1:subjects
    % read in the data from the ECG and EOG text files
    disp(['reading biopac data from subject ' ,num2str(s),'....'])
    fileName = ['BIOPAC_s',num2str(s),'.txt'];
    data = dlmread(fileName);

    % BASELINE HEART RATE DATA CALCULATIONS:
    HRbaseline = data(data(:,1) > flags(s,1) & data(:,1) <
(flags(s,1)+2),:); % first 2 min of exp
    % peak detection
```

```matlab
        [baselocs,baselocs_Rwave] =
findpeaks(HRbaseline(:,4),'MinPeakHeight',threshold(s,1),'MinPeakDistan
ce',200);
    % save baseline heartrate
    baseheartrates(s,:)=(length(baselocs)/2);
    % calculate and save the times of the baseline heart beats
    basetime=HRbaseline(:,1);
    basepeaktimes=basetime(baselocs_Rwave);

    % HEART RATE CALCULATIONS FOR ALL OTHER PERIODS:
    % switch between cases with all data and cases with missing data
    switch s
        % cases (subjects) with all data
        case
{1,2,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,
29,30,31,32,33}
            % parse the data into segments corresponding to periods
from the experiment
            i=1;
            for t = 2:2:38
                % save correct part of data to experiment variable
                experiment  = data(data(:,1) > (flags(s,1)+t) &
data(:,1) < (flags(s,1)+t+2),:);
                % switch between 1st and 2nd halves of experiment
                switch t
                    % first half
                    case {2, 4, 6, 8, 10, 12, 14, 16, 18}
                        % R wave peak detection
                        [locs,locs_Rwave] =
findpeaks(experiment(:,4),'MinPeakHeight',threshold(s,1),'MinPeakDistan
ce',200);
                    % second half, needs filtering due to interference
from pad/blanket
                    case {20, 22, 24, 26, 28, 30, 32, 34, 36, 38}
                        % filter and then R wave peak detection
                        [b,a] = butter(10, 0.1, 'low'); % 10th order
filter with normalized cutoff frequency
                        filtheart = filter(b, a, experiment(:,4));
                        [locs,locs_Rwave] =
findpeaks(filtheart,'MinPeakHeight',threshold(s,1),'MinPeakDistance',20
0);
%                       %used to graph ECG signal with identified
peaks to check for accuracy:
%                                       figure
%                                       time=experiment(:,1);
%
plot(experiment(:,1),filtheart,time(locs_Rwave),locs,'rv','MarkerFaceCo
lor','r');
%                                       axis tight
%                                       xlabel('Time');
ylabel('Voltage')
%                                       title('Find All Peaks');
%
                end
```

```matlab
                % determine the times of the peaks for each time period
                time=experiment(:,1);
                peaktimes=time(locs_Rwave);

                % before the end of this case, save what you need to
for each subject
                heartrates(s,i) = (length(locs)/2);
                percentchangeHR(s,i) = (((length(locs)/2)-
(length(baselocs)/2))/(length(baselocs)/2))*100;
                percentchangeCVRR(s,i) =
(((std(diff(peaktimes)*60)/mean(diff(peaktimes)*60))-
(std(diff(basepeaktimes)*60)/mean(diff(basepeaktimes)*60)))/((std(diff(
basepeaktimes)*60)/mean(diff(basepeaktimes)*60)))))*100;
                i=i+1;
            end

        % cases (subjects) with missing data, both only have from 0 to
20 minutes
        case {3,11}
            % parse the data into segments corresponding to periods
from the experiment
            j=1;
            for m = 2:2:18
                % save correct part of data to experiment variable
                experiment  = data(data(:,1) > (flags(s,1)+m) &
data(:,1) < (flags(s,1)+m+2),:);

                % R wave peak detection
                [locs,locs_Rwave] =
findpeaks(experiment(:,4),'MinPeakHeight',threshold(s,1),'MinPeakDistan
ce',200);

                % determine the times of the peaks for each time period
                time=experiment(:,1);
                peaktimes=time(locs_Rwave);

                % before the end of this case, save what you need to
for each subject
                percentchangeHR(s,j) = (((length(locs)/2)-
(length(baselocs)/2))/(length(baselocs)/2))*100;
                heartrates(s,j) = (length(locs)/2);
                %percentchangeSDNN(s,i) = (std(diff(peaktimes)*60)-
std(diff(basepeaktimes)*60))/std(diff(basepeaktimes)*60)*100;
                percentchangeCVRR(s,j) =
(((std(diff(peaktimes)*60)/mean(diff(peaktimes)*60))-
(std(diff(basepeaktimes)*60)/mean(diff(basepeaktimes)*60)))/((std(diff(
basepeaktimes)*60)/mean(diff(basepeaktimes)*60)))))*100;
                j=j+1;
            end
    end
    disp 'done'
end

% sort out the averages by temperature
```

```matlab
hotHR = percentchangeHR(1:3:31,:);
coldHR = percentchangeHR(2:3:32,:);
neutralHR = percentchangeHR(3:3:33,:);

hotCVRR = percentchangeCVRR(1:3:31,:);
coldCVRR = percentchangeCVRR(2:3:32,:);
neutralCVRR = percentchangeCVRR(3:3:33,:);

% fill in missing data with means
topHR = coldHR (1:3, 10:19);
bottomHR = coldHR (5:11, 10:19);
coldHR (4, 10:19) = mean ([topHR; bottomHR]);
neutralHR (1, 10:19) = mean (neutralHR (2:11,10:19));

topCVRR = coldCVRR (1:3, 10:19);
bottomCVRR = coldCVRR (5:11, 10:19);
coldCVRR (4, 10:19) = mean ([topCVRR; bottomCVRR]);
neutralCVRR (1, 10:19) = mean (neutralCVRR (2:11,10:19));

% preallocate for speed
hotHRAvgs = zeros (1,19);
coldHRAvgs = zeros (1,19);
neutralHRAvgs = zeros (1,19);

hotCVRRAvgs = zeros (1,19);
coldCVRRAvgs = zeros (1,19);
neutralCVRRAvgs = zeros (1,19);

hotHRE = zeros (1,19);
coldHRE = zeros (1,19);
neutralHRE = zeros (1,19);

hotCVRRE = zeros (1,19);
coldCVRRE = zeros (1,19);
neutralCVRRE = zeros (1,19);

i=1;
for p = 1:19
    % calculates the mean values for each time period for HR and
HRV(CVRR)
    hotHRAvgs(1,i) = mean(hotHR(:,p));
    coldHRAvgs(1,i) = mean(coldHR(:,p));
    neutralHRAvgs(1,i) = mean(neutralHR(:,p));

    hotCVRRAvgs (1,i) = mean(hotCVRR(:,p));
    coldCVRRAvgs (1,i) = mean(coldCVRR(:,p));
    neutralCVRRAvgs (1,i) = mean(neutralCVRR(:,p));

    % standard error calcuations for error bars
    hotHRE (1,i) = std(hotHR(:,p))/sqrt(11);
    coldHRE (1,i) = std(coldHR(:,p))/sqrt(11);
    neutralHRE (1,i) = std(neutralHR(:,p))/sqrt(11);
```

```matlab
    hotCVRRE (1,i) = std(hotCVRR(:,p))/sqrt(11);
    coldCVRRE (1,i) = std(coldCVRR(:,p))/sqrt(11);
    neutralCVRRE (1,i) = std(neutralCVRR(:,p))/sqrt(11);

    i=i+1;
end

% set x values for plot (# of time periods)
periods = 1:19;

% plot mean HR values over periods of watch
figure
errorbar(periods,neutralHRAvgs,neutralHRE,':kp',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotHRAvgs,hotHRE,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',10)
errorbar(periods,coldHRAvgs,coldHRE,'-.ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
xline = [9.5 9.5];
yline = [-10 2];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent HR Change','fontsize',14);
legend ('Neutral','Hot','Cold','Location','SouthWest');
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for heart rate graph
% hot condition, first half
x = 1:0.5:9.5; % set x values for first half
y = -0.35184 * x - 1.8177;
plot (x, y, 'r', 'LineWidth', 3)
% cold condition, first half
y = -0.32725 * x - 4.1207;
plot (x, y, 'LineWidth', 3)
% neutral condition, first half
y = -0.29053 * x + 0.49636;
plot (x, y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 9.5:0.5:19; % set x values for second half
y = 0.53128 * x - 10.65;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = 0.16377 * x - 8.8475;
plot (x,y, 'LineWidth', 3)
% neutral condition, second half
y = 0.015775 * x - 2.8929;
plot (x,y, 'g', 'LineWidth', 3)

% plot mean HRV (CVRR) over periods of watch
```

```matlab
figure
errorbar(periods,neutralCVRRAvgs,neutralCVRRE,':kp',...
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotCVRRAvgs,hotCVRRE,'-ks',...
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',10)
errorbar(periods,coldCVRRAvgs,coldCVRRE,'-.ko',...
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
xline = [9.5 9.5];
yline = [-40 50];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent HRV Change (CVRR)','fontsize',14);
legend ('Neutral','Hot','Cold','Location','NorthWest');
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',...
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for HRV graph
% hot condition, first half
x = 1:0.5:9.5; % set x values for first half
y = 2.1648 * x - 17.912;
plot (x, y, 'r', 'LineWidth', 3)
% cold condition, first half
y = 0.57549 * x - 19.26;
plot (x, y, 'LineWidth', 3)
% neutral condition, first half
y = 2.4568 * x - 14.623;
plot (x, y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 9.5:0.5:19; % set x values for second half
y = 0.69349 * x - 13.322;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = -0.15948 * x - 7.9069;
plot (x,y, 'LineWidth', 3)
% neutral condition, second half
y = 1.6019 * x - 0.31854;
plot (x,y, 'g', 'LineWidth', 3)



% Code to analyze EOG data for HF paper.
% AFIT Thesis
% Justine Jeroski
% 2014


clear all, close all
clc

% change directory to where the data is stored
cd I:\setup\Desktop\Justine' 'Thesis\MATLAB
```

```matlab
subjects = 33; % set the number of subjects

% read in flags (start and end of critical periods) for EOG/ECG data.
disp 'reading physiology flags spreadsheet....'
expflags = xlsread('Physiology Flags.xls', 1,
['H4:H',num2str(subjects+3)]);
disp 'done'
% convert all times to minutes
expflags = expflags / 60;

% preallocate for speed
blinkrates = zeros(subjects, 19); % blink rates for each period
PCblinkrate = zeros(subjects, 19); % percent change blink rates for
each period
IBLI = zeros (subjects, 19); % inter blink intervals for each period
PCIBLI = zeros (subjects, 19); % percent change inter blink intervals
for each period

% read in the threshold values for each subject
shiftvalue = xlsread('EOG_Blink_Thresholds', 1,
['B2:K',num2str(subjects+1)]);

for s = 1:subjects
    % read in the data from the ECG and EOG text files
    disp(['reading biopac data from subject ' ,num2str(s),'....'])
    fileName = ['BIOPAC_s',num2str(s),'.txt'];
    alldata = dlmread(fileName);

    % BASELINE BLINK DATA CALCULATIONS:
    % read in baseline time period
    experiment  = alldata(alldata(:,1) > (expflags(s,1)) & alldata(:,1)
< (expflags(s,1)+2),:);

    % filter vertical EOG signal to remove noise from pad/blanket
interference
    [b,a] = butter(10, 0.06, 'low'); % 10th order filter with
normalized cutoff frequency
    filteyevert = filter(b, a, experiment(:,2));

    % create a moving average as a threshold for blink detection
    movavg = smooth(filteyevert,1000);
    % shift up appropriate amount
    shiftedmovavg= movavg+shiftvalue(s);

    % preallocate for speed
    newfilteyevert = zeros(12000,1);

    % combine vert EOG signal and moving average lines, keeping the
larger value at each pt
    for j = 1:length(filteyevert)
        if shiftedmovavg(j) < filteyevert(j)
            newfilteyevert(j) = filteyevert(j);
        else
```

```matlab
                newfilteyevert(j) = 0;
            end
        end
    end

    % peak detection
    [baselocs,baselocs_Rwave] =
findpeaks(newfilteyevert,'MinPeakDistance',100);
    basetime=experiment(:,1);
    basepeaktimes=basetime(baselocs_Rwave);

    % BLINK DATA CALCULATIONS FOR ALL OTHER PERIODS:
    % switch between cases with all data and cases with missing data
    switch s
        case
{1,2,4,5,6,7,8,9,10,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,28,29,
30,31,32,33}

            i=1;
            for t = 2:2:38
                % read in eac time period of data
                experiment  = alldata(alldata(:,1) > (expflags(s,1)+t)
& alldata(:,1) < (expflags(s,1)+t+2),:);

                % filter vertical EOG signal to remove noise from
pad/blanket interference
                [b,a] = butter(10, 0.06, 'low'); % 10th order filter
with normalized cutoff frequency
                filteyevert = filter(b, a, experiment(:,2));

                % create a moving average as a threshold for blink
detection
                movavg = smooth(filteyevert,1000);
                % shift up appropriate amount
                shiftedmovavg= movavg+shiftvalue(s);

                % combine vert EOG signal and moving average lines,
keeping the larger value at each pt
                for j = 1:length(filteyevert)
                    if shiftedmovavg(j) < filteyevert(j)
                        newfilteyevert(j) = filteyevert(j);
                    else
                        newfilteyevert(j) = 0;
                    end
                end

                % peak detection
                [locs,locs_Rwave] =
findpeaks(newfilteyevert,'MinPeakDistance',100);

%                 % used to graph EOG signal with identified peaks to
check for accuracy:
%                                 figure
%                                 time=experiment(:,1);
```

147

```matlab
%                                    plot(experiment(:,1),shiftedmovavg,
':k')
%                                    hold on
%
plot(experiment(:,1),filteyevert,time(baselocs_Rwave),baselocs,'rv','Ma
rkerFaceColor','r');
%                                    xlabel ('Time','fontsize',14);
%                                    ylabel ('Voltage','fontsize',14);
%                                    legend ('Moving Average','Vertical
EOG Signal','Location','SouthWest');

                % save...
                blinkrates(s,i) = length(locs);
                PCblinkrate(s,i) =((length(locs)-
length(baselocs))/length(baselocs))*100;
                time=experiment(:,1);
                peaktimes=time(locs_Rwave);
                IBLI (s,i) = mean(diff(peaktimes)*60);
                PCIBLI(s,i) = (mean(diff(peaktimes)*60)-
mean(diff(basepeaktimes)*60))/mean(diff(basepeaktimes)*60)*100;


                i=i+1;

            end


        case {3, 11}

            i=1;
            for t = 2:2:18
                % read in eac time period of data
                experiment  = alldata(alldata(:,1) > (expflags(s,1)+t)
& alldata(:,1) < (expflags(s,1)+t+2),:);

                % filter vertical EOG signal to remove noise from
pad/blanket interference
                [b,a] = butter(10, 0.06, 'low'); % 10th order filter
with normalized cutoff frequency
                filteyevert = filter(b, a, experiment(:,2));

                % create a moving average as a threshold for blink
detection
                movavg = smooth(filteyevert,1000);
                % shift up appropriate amount
                shiftedmovavg= movavg+shiftvalue(s);

                % combine vert EOG signal and moving average lines,
keeping the larger value at each pt
                for j = 1:length(filteyevert)
                    if shiftedmovavg(j) < filteyevert(j)
                        newfilteyevert(j) = filteyevert(j);
                    else
                        newfilteyevert(j) = 0;
```

148

```matlab
                end
            end

            % peak detection
            [locs,locs_Rwave] =
findpeaks(newfilteyevert,'MinPeakDistance',100);

            % save...
            blinkrates(s,i) = length(locs);
            PCblinkrate(s,i) =((length(locs)-
length(baselocs))/length(baselocs))*100;
            time=experiment(:,1);
            peaktimes=time(locs_Rwave);
            IBLI (s,i) = mean(diff(peaktimes)*60);
            PCIBLI(s,i) = (mean(diff(peaktimes)*60)-
mean(diff(basepeaktimes)*60))/mean(diff(basepeaktimes)*60)*100;

            i=i+1;
        end

    case {27}
        i=1;
        for t = 2:2:14
            % read in eac time period of data
            experiment  = alldata(alldata(:,1) > (expflags(s,1)+t)
& alldata(:,1) < (expflags(s,1)+t+2),:);

            % filter vertical EOG signal to remove noise from
pad/blanket interference
            [b,a] = butter(10, 0.06, 'low'); % 10th order filter
with normalized cutoff frequency
            filteyevert = filter(b, a, experiment(:,2));

            % create a moving average as a threshold for blink
detection
            movavg = smooth(filteyevert,1000);
            % shift up appropriate amount
            shiftedmovavg= movavg+shiftvalue(s);

            % combine vert EOG signal and moving average lines,
keeping the larger value at each pt
            for j = 1:length(filteyevert)
                if shiftedmovavg(j) < filteyevert(j)
                    newfilteyevert(j) = filteyevert(j);
                else
                    newfilteyevert(j) = 0;
                end
            end

            % peak detection
            [locs,locs_Rwave] =
findpeaks(newfilteyevert,'MinPeakDistance',100);
```

```matlab
                % save...
                blinkrates(s,i) = length(locs);
                PCblinkrate(s,i) =((length(locs)-
length(baselocs))/length(baselocs))*100;
                time=experiment(:,1);
                peaktimes=time(locs_Rwave);
                IBLI (s,i) = mean(diff(peaktimes)*60);
                PCIBLI(s,i) = (mean(diff(peaktimes)*60)-
mean(diff(basepeaktimes)*60))/mean(diff(basepeaktimes)*60)*100;

                i=i+1;

            end
    end

    disp 'done'
end

% sort out the averages by temperature
% blink rate
hotPCblinkrate = PCblinkrate(1:3:31,:);
coldPCblinkrate = PCblinkrate(2:3:32,:);
neutralPCblinkrate = PCblinkrate(3:3:33,:);

% fill in missing values with means
topcoldBR = coldPCblinkrate (1:3, 10:19);
bottomcoldBR = coldPCblinkrate (5:11, 10:19);
coldPCblinkrate (4, 10:19) = mean ([topcoldBR; bottomcoldBR]);

topneutralBR1 = neutralPCblinkrate (2:8, 10:19);
bottomneutralBR1 = neutralPCblinkrate (10:11, 10:19);
neutralPCblinkrate (1, 10:19) = mean ([topneutralBR1;
bottomneutralBR1]);

topneutralBR2 = neutralPCblinkrate (1:8, 7:19);
bottomneutralBR2 = neutralPCblinkrate (10:11, 7:19);
neutralPCblinkrate (9, 7:19) = mean ([topneutralBR2;
bottomneutralBR2]);

% inter blink interval
hotPCIBLI = PCIBLI(1:3:31,:);
coldPCIBLI = PCIBLI(2:3:32,:);
neutralPCIBLI = PCIBLI(3:3:33,:);

% fill in missing values with means
topcoldIBLI = coldPCIBLI (1:3, 10:19);
bottomcoldIBLI = coldPCIBLI (5:11, 10:19);
coldPCIBLI (4, 10:19) = mean ([topcoldIBLI; bottomcoldIBLI]);

topneutralIBLI1 = neutralPCIBLI (2:8, 10:19);
bottomneutralIBLI1 = neutralPCIBLI (10:11, 10:19);
neutralPCIBLI (1, 10:19) = mean ([topneutralIBLI1;
bottomneutralIBLI1]);
```

```matlab
topneutralIBLI2 = neutralPCIBLI (1:8, 7:19);
bottomneutralIBLI2 = neutralPCIBLI (10:11, 7:19);
neutralPCIBLI (9, 7:19) = mean ([topneutralIBLI2; bottomneutralIBLI2]);

% preallocate for speed
hotBlinkrateAvgs = zeros (1,19);
coldBlinkrateAvgs = zeros (1,19);
neutralBlinkrateAvgs = zeros (1,19);

hotBlinkrateError = zeros (1,19);
coldBlinkrateError = zeros (1,19);
neutralBlinkrateError = zeros (1,19);

hotPCIBLIAvgs = zeros (1,19);
coldPCIBLIAvgs = zeros (1,19);
neutralPCIBLIAvgs = zeros (1,19);

hotPCIBLIError = zeros (1,19);
coldPCIBLIError = zeros (1,19);
neutralPCIBLIError = zeros (1,19);

k=1;
for p = 1:19
    % calculates the mean values for each time period for blink rate
    hotBlinkrateAvgs(1,k) = mean(hotPCblinkrate(:,p));
    coldBlinkrateAvgs(1,k) = mean(coldPCblinkrate(:,p));
    neutralBlinkrateAvgs(1,k) = mean(neutralPCblinkrate(:,p));
    % calculates the mean values for each time period for inter blink
intervals
    hotPCIBLIAvgs(1,k) = mean(hotPCIBLI(:,p));
    coldPCIBLIAvgs(1,k) = mean(coldPCIBLI(:,p));
    neutralPCIBLIAvgs(1,k) = mean(neutralPCIBLI(:,p));

    % standard error calcuations for error bars
    hotBlinkrateError (1,k) = std(hotPCblinkrate(:,p))/sqrt(11);
    coldBlinkrateError (1,k) = std(coldPCblinkrate(:,p))/sqrt(11);
    neutralBlinkrateError (1,k) =
std(neutralPCblinkrate(:,p))/sqrt(11);

    hotPCIBLIError (1,k) = std(hotPCIBLI(:,p))/sqrt(11);
    coldPCIBLIError (1,k) = std(coldPCIBLI(:,p))/sqrt(11);
    neutralPCIBLIError (1,k) = std(neutralPCIBLI(:,p))/sqrt(11);

    k=k+1;
end

% set x values for plot (# of time periods)
periods = 1:19;

% plot mean blink rate values over periods of watch
figure
```

151

```matlab
errorbar(periods,neutralBlinkrateAvgs,neutralBlinkrateError,':kp',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotBlinkrateAvgs,hotBlinkrateError,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',10)
errorbar(periods,coldBlinkrateAvgs,coldBlinkrateError,'-.ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
%vertical line at the tempearture change
xline = [9.5 9.5];
yline = [-20 160];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
ylabel ('Percent Blink Rate Change','fontsize',14);
legend ('Neutral','Hot','Cold','Location','NorthWest');
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for blink rate graph
% hot condition, first half
x = 1:0.5:9.5; % set x values for first half
y = 8.0282 * x - 5.821;
plot (x, y, 'r', 'LineWidth', 3)
% cold condition, first half
y = 4.0573 * x + 1.217;
plot (x, y, 'LineWidth', 3)
% neutral condition, first half
y = 8.4025 * x + 17.067;
plot (x, y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 9.5:0.5:19; % set x values for second half
y =-1.2034 * x + 66.883;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = 1.1054 * x + 25.462;
plot (x,y, 'LineWidth', 3)
% neutral condition, second half
y = 1.0113 * x + 71.436;
plot (x,y, 'g', 'LineWidth', 3)

% plot mean interblink intevals over periods of watch
figure
errorbar(periods,neutralPCIBLIAvgs,neutralPCIBLIError,':kp',
'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',10)
hold on
errorbar(periods,hotPCIBLIAvgs,hotPCIBLIError,'-ks',
'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',10)
errorbar(periods,coldPCIBLIAvgs,coldPCIBLIError,'-.ko',
'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',10)
%vertical line at the tempearture change
yline = [-50 30];
plot(xline,yline, 'k')
xlabel ('Time on Task (Minutes)','fontsize',14);
```

```matlab
ylabel ('Percent Interblink Interval Change','fontsize',14);
legend ('Neutral','Hot','Cold','Location','SouthWest');
set(gca,'XTick',1:19)
set(gca,'XTickLabel',{'2-4', '4-6', '6-8', '8-10', '10-12', '12-14',
'14-16', '16-18', '18-20',...
    '20-22', '22-24', '24-26', '26-28', '28-30', '30-32', '32-34', '34-
36', '36-38', '38-40'});

% plot trend lines for interblink intervals graph
% hot condition, first half
x = 1:0.5:9.5; % set x values for first half
y = -2.047 * x + 10.792;
plot (x, y, 'r', 'LineWidth', 3)
% cold condition, first half
y = -2.8221 * x + 7.1877;
plot (x, y, 'LineWidth', 3)
% neutral condition, first half
y = -1.9693 * x - 3.0625;
plot (x, y, 'g', 'LineWidth', 3)
% hot condition, second half
x = 9.5:0.5:19; % set x values for second half
y = 0.026348 * x - 8.393;
plot (x,y, 'r', 'LineWidth', 3)
% cold condition, second half
y = -0.031798 * x - 11.732;
plot (x,y, 'LineWidth', 3)
% neutral condition, second half
y = -1.4811 * x - 7.5734;
plot (x,y, 'g', 'LineWidth', 3)
```

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to an penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 27-03-2014	2. REPORT TYPE Master's Thesis	3. DATES COVERED (From – To) October 2012 – March 2014

4. TITLE AND SUBTITLE Physiological Investigation of Localized Temperature Effects on Vigilance Performance	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Jeroski, Justine D, Ms.	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way Wright-Patterson AFB OH 45433-7765	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENV-14-M-30

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFRL) Wright-Patterson AFB OH 45433 937-255-8887 and lloyd.tripp@us.af.mil ATTN: Lloyd D. Tripp	10. SPONSOR/MONITOR'S ACRONYM(S) 711th HPW/RHC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release; Distribution unlimited.

13. SUPPLEMENTARY NOTES
This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

14. ABSTRACT

Despite a long history of vigilance research, the relationship between the vigilance decrement and a broad range of physiology measures has not been fully documented. In an attempt to address this gap, an experiment was designed in which participants detected critical signals displayed at random during a 40-minute simulated air traffic control vigilance task. Three localized temperature condition changes, a positive, negative, or no change, were randomly assigned to participants and administered at the halfway point of the task. In addition to collecting performance data, cerebral oximetry, electrocardiography (ECG), and electrooculography (EOG) were utilized to collect a range of physiological signals from participants including cerebral oxygenation levels, heart rate, heart rate variability, blink rate, and interblink intervals. The physiology data when correlated with the decrement indicated by the performance data demonstrated a potential relationship between these measures. By identifying a vigilance decrement in individuals, one or more physiology measures may aid the design of interactive vigilance displays and compensatory measures for overcoming the vigilance decrement.

15. SUBJECT TERMS
vigilance decrement, performance, cerebral oximetry, electrocardiography, electrooculography

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Miller, Michael E., PhD, Research Advisor
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	165	19b. TELEPHONE NUMBER (Include area code) (937)-785-3636 x 4651 Michael.Miller@afit.edu

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18